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SEISMIC SHOCKS AND THEIR EFFECTS
ON REINFORCED CONCRETE FOOTINGS
AND FOUNDATIONS

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SEISMIC SHOCKS
And Their Effects On
REINFORCED CONCRETE
FOOTINGS AND FOUNDATIONS

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INTRODUCTION

One of the newer areas of scientific research in the past fifty years is in the field of seismology -- the study of earthquakes. In spite of the amount of research done, a great deal remains to be learned in this field. It still is not known just why earthquakes occur and what happens in the earth when a seismic disturbance takes place; nor is it possible to predict in advance when an earthquake will take place. To date, many theories have been put forth concerning these questions, but none of these have been definitely proved.

Even less has been done on the engineering side of the picture. Most architects and engineers realize that earthquake forces must be taken into consideration when designing structures, but few realize exactly why and how these affect the structure. The architect most often uses the "cookbook" approach when entering this stage of the structural design. This point is well illustrated by a passage from Clarence W. Dunham's textbook, Foundations of Structures. This passage, "Special Forces", reads in part:

"These forces are difficult to estimate and should be included in one's analysis only in regions where seismic shocks are probable. If the structure is on rock, the vertical forces from earthquake shocks may be neglected as far as piers and abutments are concerned, and the horizontal forces may be assumed to be equal to 10 per cent of the weight of the superstructure (D. L.) acting at its estimated center of gravity. If the superstructure is supported upon deep soil, whether granular or cohesive, and whether piers are used or not, the shocks from earth-

quakes are likely to be more serious since the soil may magnify, somewhat, the vibrations. The earthquake problem is one deserving careful study. In most cases, it is probably best to build a structure that is basically strong in its resistance to earthquakes."

In writing this thesis, I am trying to correlate some of the recent developments in the field of seismology with the structural design of buildings, putting specific emphasis on the footings and foundations of the structure. The approach taken deals, in the first part, with the soil mechanics involved with seismic shocks. Once these conditions are shown, the results will then be applied to the footings and foundations of the structure.

This paper, by no means, offers any solution to the problems facing the structural engineer when he is confronted with the seismic force problem, but is meant to be more of a critical survey in the field of seismic research.

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CHAPTER I

GEOGRAPHIC ANALYSIS

Since the beginning of recorded history, earthquakes have always received considerable mention. Because of earthquakes, whole civilizations have been wiped off the face of the earth. Many ancient Roman cities along the western coast of Italy were completely destroyed because of seismic disturbances.

The cause of earthquakes has not been found and can only be studied after the quake has occurred. This makes the study of seismic shocks somewhat difficult.

Earthquakes occur in all parts of the world but certain areas seem more "earthquake prone" than do others. The distribution of earthquakes throughout the world was studied thoroughly by Comte de Montessus de Ballore in the early part of this century. He accumulated a catalog with approximately 171,000 entries. This catalog is, at present, in the library of the Societe de Geographic in Paris.

As a result of his studies, Montessus noticed that the great majority of earthquakes occurred in two great circle zones which encompass the earth. One of these zones passes through the East Indies, the Himalayas, the Caucasus, the Alps and the West Indies. The other zone encircles the Pacific Ocean. According to his records, about 54 per cent of the earthquakes on record occurred in the former zone and about 40 per cent in the latter. This was the record of earth-

quakes up to about 1906. To Montessus also goes the credit for establishing the fact that the greater the gradient of the earth's crust, the greater the possibility of earthquakes occurring in that area.

Today, however, Montessus' records are not considered to be completely accurate. Most scientists feel that if an earthquake has not been recorded on instruments, it is not an earthquake. Today the standard catalog of earthquakes is "The Seismicity of the Earth" by Gutenberg and Richter and this catalog is based on instrumental data from about 1900 to date.

The zones defined by Montessus are verified by Gutenberg and Richter but the earthquake distribution has changed somewhat. Gutenberg and Richter find that 80 per cent of shallow shocks (depth of focus no more than 60 km.), 90 per cent of intermediate depth shocks (depth of focus 70 to 300 km.), and all but one deep shock have occurred in the circum-Pacific zone. The Mediterranean and trans-Asiatic zone contain nearly all the others. In these cases, the 'focus' of the earthquakes is the point in the earth that is the exact center of the quake, as distinguished from the 'epicenter', which is the point on the surface of the earth directly over the focus.

Since the Pacific Coastal States and the Rocky Mountain States of this country fall roughly in the circum-Pacific earthquake zone, it is interesting to look into the seismicity of these areas. The Pacific Coastal States are California, Oregon and Washington. The Mountain

or Inland States are Nevada, Arizona, Utah, Idaho, Montana, New Mexico, Wyoming and Colorado.

The Pacific Coastal States

California:

California ranks number one on the seismicity list of all western states. Although all parts of California experience occasional seismic disturbances, these disturbances occur most often in a definite zone. At the northern end of the state the zone is off the coast. Occasionally, there is a shock in this area with its epicenter inland, and shocks do considerable damage. To the south of this area, the San Andreas Fault runs through Mendocino, Sonoma and Marian counties. Since this portion of the fault experienced the largest displacements observed in 1906, it is possible to trace the California earthquake zone along it even though this area has remained comparatively free from earthquakes since 1906.

Moving south along the fault line, the earthquake zone begins to move inland. South of the Golden Gate, this zone swings into and begins to follow the Coast Ranges. Earthquakes in this area always have their epicenter inland. Earthquakes, both small and moderate, are quite frequent. This area, the San Francisco Bay area, experienced strong shocks in 1836, 1838, 1865, 1868, 1906. However, none of these shocks were recorded on instruments. Continuing southward, the zone turns

with the geologic structure and the coast line near Santa Barbara County. The width of the zone in this area is approximately that of the mountain belt. In this area, Santa Barbara County, the San Andreas Fault was the seat of a very strong earthquake in the year 1857. The Tehachapi earthquake of 1952 was in the northern part of this area and the Santa Barbara quake of 1925 had its epicenter in the southern part of this area.

Continuing still further southward, the zone begins to widen. In the vicinity of Los Angeles County, the zone covers the area from the coast line to the Great Valley (Imperial Valley). In 1857, a strong quake occurred whose epicenter was located in the northern part of this area. The Long Beach earthquake of 1933 had its epicenter in the southern part of the area along the coast. After leaving Los Angeles and Orange counties, the zone swings still further inland, into the Imperial Valley. However, the disastrous earthquake at San Juan Capistrano in 1812 seems to indicate that a part of the zone continues down the coast. Once in the Imperial Valley, which has been the seat of many destructive earthquakes of this century, the zone continues almost due south and runs into Mexico.

Because of this zone effect, the central valley of California is almost completely free of epicenters. However, effects of quakes with epicenters in the Coast Ranges sometimes produce damage in this area.

The eastern borders of the southern Sierra Nevada also have a good deal of seismic activity. The earthquake of 1872 on the Owens Valley Fault is particularly notable. Large shocks also occur to the north of this region on the eastern side of the Sierra, sometimes over the boundary in Nevada. Further north, in Modoc County, seismic shocks are rare, but there is no place in the state that is completely free of shocks.

It might be added that the seismic history of California is fairly complete since earthquake records began being kept in 1769 by the Spanish.

Oregon:

Oregon presents somewhat of a puzzle as far as earthquake zoning is concerned. Although the earthquake zone runs off the Oregon coast, there have been relatively few severe shocks in this state. Records have been kept for about one hundred years but only four serious shocks have been recorded in this time. The total number of seismic disturbances on record is about 125, dating from 1866 to 1950.

Washington:

The state of Washington is the fourth most seismic state of the western United States. The earthquake history of the state began in 1833 with a record of a slight shock at Fort Nisqually. Most of the recorded shocks have occurred in the Puget Sound area. This is because of the extension of a very active earthquake zone extending down from the Queen Charlotte and Vancouver Islands.

The Inland States

Nevada: Nevada is quite active seismically and is considered to be second to California in seismicity. The first shock recorded in the state was "very strong" in the Carson City area in 1860. This same shock was also felt in California and Utah. Since the population of Nevada is not very dense, many shocks have occurred in the state that probably were not reported. In the period from 1860 to 1952, some 568 earthquakes have been reported as having their epicenters in the state. Of these, 13 were considered damaging. All of these larger shocks have occurred in the western half of the state. If an earthquake zone were to be constructed in this state, it would lie on the eastern flank of the Sierra Nevada and extend north from the Owens Valley in California. There would also be another north-south zone running from the Excelsior Mountains in the south to Pleasant Valley in the north. In 1915, Pleasant Valley was the epicenter of a great quake in which great surface ruptures, or faults, occurred. In December of 1954, spectacular faulting occurred in the Dixie-Valley-Fairview Peak area. In 1932 in the Cedar Mountains and again in 1934 in the Excelsior Mountains, minor faulting took place. In the Fallon earthquakes of 1954, minor faulting also occurred.

Arizona:

This state has been relatively free of seismic activity. From 1850, when records began, to 1952, only about 35 earthquakes have

had their epicenters in the state. California Shocks are occasionally felt in Arizona. The Sonora, Mexico shock of 1887 was felt throughout the state. However, only four shocks with their epicenters in Arizona have been of intensity VII (Modified Mercalli Scale, See Appendix A) or greater. If an earthquake zone were to be plotted for the state, it would start in the north-central part of the state and run northward into Utah, along the Idaho-Wyoming border and into central Montana.

Utah:

This state is the third most seismic state of the western States. However, the earthquake record in the state is comparatively short, dating back only to 1853. The total number of shocks on record from 1853 to 1952 is about 250, with only 13 of those considered damaging.

Idaho:

This state has been relatively free of earthquakes, with only 33 shocks on record and, of these, only 3 were considered to have been damaging.

Montana:

The state of Montana ranks fifth on the seismicity list. The first recorded seismic shock occurred in 1869, with its epicenter located in the Helena valley. Since that time there have been 8 shocks that have been considered damaging. All of the seismic activity in this state has occurred in the western half of the state.

New Mexico:

Seismic records have been kept in this state since 1868. Since that time, the total number of recorded shocks has been about 60. Of these, approximately 7 are considered to have been damaging. In 1906 and 1907, hundreds of shocks were felt in Socorro and surrounding areas, but only three were considered to have centered in that area. In 1904 there was another month-long series of earthquakes at Socorro.

Wyoming and Colorado:

These states are the least active, seismicly, of the Inland group. Wyoming has no recorded earthquakes and Colorado has on record only one that was strong enough to do any damage.

All of the above history has been consolidated in Figures 1 through 11. In the map of each state appears three numbers. The first gives the number of earthquakes whose intensity was 4 or less. The second number represents those shocks of intensity 5 and 6, while the last number represents those shocks of intensity above 6. All the intensities are measured on the Modified Mercalli Scale. Each state was also rated seismically. California was arbitrarily assigned a seismicity rating of 10 and the other states were compared to California and rated accordingly. Clearly California leads. It is true that the earthquake history of this state is longer than that of any other state -- the first entry being dated in 1769 and the nearest rival, Nevada, being dated 1860. However,

the seismicity of the other states could be doubled and California would still lead.

Also on the maps are shown the probable earthquake zones, the major faults or ruptures, and the location of major seismic shocks.

From the study of the hypothetical earthquake zones as plotted on Figures 1 through 11, it can be seen that the surface of the earth rises to great heights or dips to extremely low levels, as in the ocean floor off the California and Oregon coast. This rise and fall of the surface, or crust, of the earth is known as a change in gradient of the earth's crust. The gradient is measured as the angle at which the crust layer rises and falls. Where there is a large angle of rise or fall, i. e. a steep gradient, earthquakes seem to occur more often. This phenomenon was first noted by Montessus and seems to hold true in most cases. However, this gradient phenomenon does not preclude the fact that earthquakes can occur where the gradient is very shallow. As a result, the theory has not been definitely established. Nevertheless, the change in gradient can be used in measuring or establishing probable earthquake zones with a fair degree of accuracy.

CHAPTER 2

THE EARTHQUAKE WAVE

The exact nature and properties of the earthquake wave are not known. However, the wave is known to have most of the same properties that other moving waves in a compressible medium have. That is, the earthquake wave has acceleration, period and amplitude. Beyond this point, the properties of the wave are more or less unknown.

The earthquake, or seismic, waves move through the earth in the same manner that most wave motions travel. At the beginning of the wave, or source, a vibration is set up. From the source, the wave begins to move outward by exciting particles of the earth. The movement of the earth particles is passed along to other particles. Soil particles are, for the most part, very compressible. From all observations, the wave moves with a fairly constant speed. However, in very granular soil, where there is a loose bond between particles, the strength of the wave seems to be magnified. The opposite is true for extremely dense soil, such as rock or heavy clay. These soils tend to diminish the strength of the wave. At any rate, the soil in most earthquake zones seems to be a good propogating agent.

From seismographic records, it has been found that an earthquake wave has both vertical and horizontal movement, with the latter being the stronger and more pronounced. The vertical motion is what produces the heaving effect in the earth. If this motion is strong enough, it can be particularly disastrous to buildings. The vertical ground

motion is also responsible for the noise, or roar, that sometimes accompanies an earthquake. However, a large vertical wave is usually the stronger and this is the wave that is usually considered when earthquake resistance is designed into a structure. This wave moves at a rapid rate and can result in extremely strong forces being developed in the earth.

Some notable examples of this vertical and horizontal wave motion, with resulting ground motion, are seen in the earthquakes of: Fort Tejon, California, 1857. In this earthquake, the vertical and horizontal displacements of the earth were extremely large but they were, for the most part, unrecorded. The vertical displacement is known to have extended for approximately 200 miles along the San Andreas Fault.

Owens Valley, California, 1872. This earthquake is quite remarkable when it is considered that the vertical displacement was greater than the horizontal displacement. In this earthquake, the break line, or fault, extended for a distance of approximately 40 miles. During this quake, the vertical displacements were as large as 23 feet. The largest horizontal displacements recorded were 18 feet.

San Francisco, California, 1906. This shock is considered to be one of the most destructive of this century. In this shock, the San Andreas Fault broke for a length of approximately 270 miles. The displacement in the quake was almost purely horizontal. The maximum displacement

observed was 21 feet at the head of Tomales Bay. During this shock, the westerly side of the fault moved north relative to the easterly side. Imperial Valley, California, 1940. This was another earthquake with conspicuous horizontal movement. The break in the earth extended for some 40 miles and in places amounted to 15 feet in width. In this shock, the side to the west of the break moved north relative to the east side.

The earthquake wave is considered to be a moving wave and, therefore, exerts a moving force. This fact brings the structural engineer, when analyzing the structure, into the field of dynamics. Even though earthquakes and the effects produced by them are dynamic in nature, the complexity of the analysis of even the simplest of structures on the basis of dynamic response renders such an analysis completely impractical, in most cases, for ordinary office practice. Instead, it is common practice to substitute for the dynamic forces static forces which, it is assumed, will produce the same stresses and deflections in the structure as the anticipated dynamic forces.

For the purpose of simplification, the earthquake wave can be considered analogous to the sound wave in the way it travels and the effect that is produced. Like the sound wave, the earthquake wave originates at a point source, theoretically, and this point is known as the focus. From this source, the wave travels outward, in all directions. The wave travels by exciting nearby particles, setting them to vibrating. This vibrating is transferred from particle to particle by

sympathetic vibration. Whereas the usual effect of sound waves, when an immovable object is struck, is heat, the earthquake wave is of such a magnitude that no object is considered immovable and the object struck is set to vibrating, to a greater or lesser degree, depending on the inertia of the object.

As stated before, the vertical wave is the more destructive, since it causes violent ground motion. This wave and the resultant ground motion originates as a series of slips in the earth in extensive earthquake or fault zones. The slips occur in a manner similar to a chain reaction. Each slip gives birth to a seismic wave that traverses a number of geologic formations before it affects an engineering work. Nearly all of these formations are very irregular, especially in seismic regions and each seismic wave must undergo countless reflections, refractions and irregular dispersion in its travel. It reaches the structure, no longer as a single wave, but as a series of elemental pulses whose distribution in time is highly sensitive to the exact location of the slip and to many other variables. Consequently, the detailed characteristics of seismic waves of equal intensity are quite different, even when their force and places of registration coincide.

CHAPTER 3

EARTHQUAKE CAUSES

Explanations and Theories:

One theory assumes that all earthquakes are caused by a slipping between two rock surfaces on a plane deep within the surface of the earth. However, the cause of the slipping cannot be determined, since it occurs deep within the earth. This theory is called the "Tectonic" theory. This term is used to denote the structure of the earth. It might be added that, today, most seismologists disregard this theory.

In its stead, the most accepted theory explaining earthquakes is the "Elastic Rebound Theory". This theory uses parts of the "Tectonic" theory but attempts to give the cause of the slipping. This "Elastic Rebound Theory" is the work of Harry Fielding Reid. According to this theory, energy of elastic strain is stored in rock layers due to stresses set up by differential loading, temperature changes, or other factors, and when the stresses become too great a rupture occurs. This rupture, when it is seen on the surface, is known as a fault; that is, the rock on one side of the fault is displaced from that on the other side. During the formation of a fault, the two sides slide against each other and the energy of elastic strain is released in the form of elastic waves. These waves are propagated, as mentioned before, through the earth, forming an earthquake. Seismologists believe that a fault begins with a rock rupture at one point and subsequently spreads from that point to form a longer break.

Reid also advanced causes for the build-up of the elastic strain.

These causes are believed to be:

1. Volcanic action. This condition is believed to set up the elastic strain in rock layers when the molten core of the earth tries to expand through the crust of the earth. Shrinkage of the earth's crust attributes the existence of mountain chains and ocean depths to the shrinkage of the earth's interior with loss of heat and consequent wrinkling of the earth's surface, the changes being sufficient to produce a build-up of elastic strain with resulting earthquakes.
2. Erosion and deposition. This theory supposes that the change in load over a rock layer by the addition or removal of soil due to erosion or deposition is sufficient to cause elastic strain build-up.
3. Radioactivity. The hypothesis of the radioactivity of certain rocks due to the presence of radium bearing minerals would cause heat to be continuously given off which could not readily escape. This build-up of heat supposedly would be sufficient to cause a build-up of elastic strain.

As stated, the "Elastic Rebound Theory" is accepted by most seismologists as the explanation of earthquakes. Figure 12 shows a hypothetical graph of strain release as plotted for New Zealand.

CHAPTER 4

STRONG-MOTION RECORDING

Until recent years, one of the stumbling blocks to development of earthquake engineering on the most rational basis was lack of reliable information on earthquake motions against which structures should be designed. To obtain this information, strong-motion seismographs were designed, and installed in seismically active areas of the western United States. As the records produced by these instruments are more and more being used as a basis for further research and as indicators of earthquake forces, a knowledge of the instruments and their product is very useful to structural engineers when evaluating seismic forces.

Generally speaking, the strong-motion program for the United States began at the 1929 World Congress of Tokyo. During the Congress, American engineers were given the opportunity to study work of the Japanese Earthquake Research Institute and of other organizations in applying earthquake knowledge to design of structures. As a result, many returned to this country convinced that the United States should focus more attention on the engineering aspects of seismology, in particular on the development of suitable instruments for recording earthquake motions responsible for damage. In 1931, Federal aid was made available and the U. S. Coast and Geodetic Survey embarked on a program of developing suitable earthquake recording instruments.

N. H. Hect, Chief, Division of Geomagnetism and Seismology, U. S. C. G. S., had this to say about the project:

"The chief purpose of the work is for the benefit of architects and engineers. It has been felt that they should say what they want and the general consensus of opinion that has been obtained from them is that recording should start at the point where slight damage begins and such records should have sufficient amplitude for interpretation. The upper limit should be that recording of acceleration for as wide a range as the design of the instrument permits and the upper limit should exceed 2/10 of the acceleration of gravity. The information desired includes the acceleration, the period, and the amplitude of ground motion".

Guided by these criteria, employees of the Survey, assisted by those of other Government agencies and of universities, developed the several types of strong-motion seismographs which, with relatively minor changes, are in use today.

Seismographs:

Though differing in mechanical detail and thus in appearance, all seismographs are fundamentally alike. Each contains one or more pendulums, a starting device, a timing device, a recorder, and control relays. Of these component parts, only the pendulums need be considered for an understanding of the results. The other devices merely insure that the differential motion between pendulum and earth is plotted instant by instant against time to form a permanent record.

If it were possible to view ground motion during an earthquake from a fixed point in space, a facsimile of displacement could be recorded and velocity and acceleration derived by methods of differentiation. Pendulums approximate such a vantage point and in some ways improve the view. Ground motion is seen as from a movable point,

whose motion can be predicted and adjusted within certain limits. A theoretically perfect pendulum is one which is free to oscillate without friction about an axis fixed relative to the earth, and which is subjected to a restoring torque precisely proportional to the pendulum displacement at any instant and a damping torque precisely proportional to the pendulum velocity, both displacement and velocity being relative to the earth. Actual physical pendulums, to be of value as a means of recording earth motion, must closely approach the performance of theoretically perfect pendulums.

Although basically alike, pendulums may differ greatly in some of their characteristics. By properly choosing these characteristics, pendulums can be designed to record either the accelerations or the displacements of ground motion occurring at periods within their selected limits. The limits selected for Survey instruments have been from about 0.1 sec. to 5 sec. -- a range within which the natural period of most buildings fall.

Also incorporated in the U. S. C. G. S. strong motion seismographs is a device which measures the acceleration of the seismic wave. This instrument is called an Accelerograph. It works on the same basic principle as the seismograph; that is, the use of the pendulum. However, the accelerograph pendulum has a period that is very short in comparison to the displacement pendulum. Figure 13 shows a typical accelerograph record.

A definite program is now underway to make significant improvements in instrumental design and to increase the coverage of potential earthquake areas with more instruments. This program will include:

1. Design and distribution of simple oscillators with the damping and period characteristics of many common structures.
2. Redesigned strong-motion seismographs for (a) single recording with a time record and (b) multiple recording with a time record.
3. Plans for other instruments, not necessarily seismographs, that may furnish additional information or the same information in more usable form to earthquake engineering.

The simple oscillators are intended to leave records of maximum responses to earthquake motion and thus measure intensity in a form physically related to structural dynamics. They will supplement, not replace, strong-motion seismographs.

The redesign of strong-motion seismographs is intended to accomplish several things. Many of the Survey's so-called accelerographs now in use are being remodeled to incorporate displacement meters. This is possible at reasonable cost. New instruments, however, cost \$6,000 to \$8,000 to build when let out on contract in small lots. It is believed that by simplifying the design, an instrument can be constructed for much less than this to give the same information without sacrifice of precision, but perhaps of elegance. By additional sacri-

fice of the vertical component and re-cycling system it is believed that single-operation strong-motion seismographs may be mass-produced for even less. The latter instruments are intended for use at different levels in structures and to replace substandard instruments now in use.

Other plans under consideration for future work include recording on magnetic tape, development of longer-period strong-motion seismographs, and utilizing a technique now being employed with success to forecast rock bursts in deep mines. Rock burst forecasting is based on a premise that rock is under excessive strain before rupture and in this strained condition produces diagnostic sounds that can be detected by suitable geophones. The same technique applied to deep wells along active faults may conceivably result in eventual forecasting of earthquakes along these faults.

In calculating the resistivity of a structure against earthquakes, the seismic force is usually represented as a static horizontal force. This static force should be such as would give rise to the same deflection as that due to earthquake. It is therefore equal to the product of the local mass of the structure and the spatial acceleration of that mass. The spatial acceleration is the algebraic sum of the acceleration of the earthquake and the acceleration due to the deflection of the structure; so it depends both on the wave form of the earthquake and on the vibrational characteristics of the structure, such as the period, mode, and damping.

The newest discovery for recording these characteristics of the earthquake wave is the accelerograph as designed by the "Strong Motion Acceleration Committee". This committee was established in 1951 for the purpose of promoting research on the seismic horizontal force to be used in building design.

This instrument starts automatically to record earthquakes when they are greater than 10 gals (1 gal = 1 MM/SEC/SEC.) in acceleration and stops recording automatically after a three minute running period. The time marking clock starts and stops at the same time. This automatic action will repeat itself for three successive earthquakes. Ordinarily, the action is started upon a signal from the electric starter, but, in addition, a mechanical starter is provided in the driving spring motor in case of electric starter malfunction. An elinvar spring is used in the electric starter to eliminate the effect of temperature change.

The recording is made by scratching a belt of wax paper by a sapphire-tipped needle. By this means, a very sharp record is obtained which enables direct printing upon photographic paper, or photographic enlarging up to ten times the original.

The instrument has a very strong air-tight cover to protect the mechanisms from dust, humidity and falling objects in case of disastrous earthquakes. Four FM-III and four FM-V dry cells are held in a pocket box of the cover and serve as the electric source for the starter.

The overall dimensions of the instrument are 56 cm x 74 cm x 84 cm.

The special merit of this instrument is the ability to record as perfectly as possible the acceleration of earthquakes as large as 1000 gals with large recording speed; to continue operable; and to record automatically two more of the aftershocks. Ease of maintenance was considered in the design. The instrument requires a careful inspection by an expert only once a year, together with additional bi-monthly attention of a less skilled mechanic.

CHAPTER 5

WAVE INVESTIGATION.

In determining the actual effects of seismic forces on a structure, a curve called the earthquake spectrum is of great value. An earthquake spectrum is constructed by plotting the period of vibration of a structure against the maximum displacement, maximum velocity, maximum acceleration, or maximum stresses produced by a given shock. The resulting curves are called, respectively, the displacement spectrum, velocity spectrum, acceleration spectrum and stress spectrum, and if any one of them is plotted, the others can be calculated from the curve.

The data for plotting the spectra are usually obtained by placing simplified models of a structure on a shaking table and taking the required measurements. In some cases, large shaking machines are used to transmit a controlled shock to an actual structure.

The expression for the effect that an earthquake produces on an average type of structure takes the integral form:

$$S = \int_0^t a e^{-n \frac{2\pi}{T}(t-\tau)} \sin \frac{2\pi}{T}(t-\tau) d\tau$$

in which $S =$ the particular effect at time t

$a =$ base wave acceleration

$n =$ fraction of critical damping

T = period of vibration of the structure

Y = a time parameter which disappears in the course of integration.

If, for a given earthquake, all of the values for the above expression are known, then displacements, shears, bending moments, etc., can all be calculated for any structure.

The formula shown would require direct numerical integration, which can be carried out by any of the standard techniques. Various high speed digital computing machines could probably be used to advantage for such calculations. A second method would involve some graphical integration system, of the use of an instrument such as the integrator. The most commonly used techniques, however, have involved analog computing methods, several of which are well suited to problems of this kind.

The first analog technique to be applied was the torsion pendulum direct mechanical analog used by M. A. Biot, who calculated some earthquake spectra in this way. The main difficulties involved in the torsion pendulum are the inconveniences of changing the basic parameters of period and damping in the mechanical system, and the relatively long time required to obtain the complete spectrum curves in the desired detail. It is also difficult to control the damping with sufficient accuracy and to reduce it to as low a value as might be desired for some applications.

These difficulties were overcome by a much improved system developed by R. Takahasi, of the Earthquake Research Institute of Tokyo University, in which a moving coil galvanometer element was used as the mechanical torsional system. In this system, the torsional element has a fixed frequency and period changes are obtained by changing the speed of the film drive mechanism in the ground motion function generator. By arranging for an energy input into the torsional system through a feedback system, the effective damping can be reduced to zero if desired.

The operational type of electric analog computer has also been applied to the problem. It has been shown that there is a way of applying a commercial electronic differential analyzer to the determination of response spectra. A special purpose spectrum analyzer, using electronic operational techniques has also been devised.

The method which has so far been most extensively used for earthquake response spectrum determination employs the direct electric analog computer. In this type of computer, a series electrical circuit consisting of an inductance, a capacitance, and a resistance, forms a direct analogy to the mechanical single-degree-of-freedom system. The ground acceleration record is reproduced as an electric signal by means of a variable width film and photocell arrangement, and response characteristics are measured as voltages at various points in the circuit. The advantages of this method are:

1. Parameter changes can be made with ease.
2. The speed of operation is such that complete spectra can be determined in a matter of minutes.
3. Zero damping can be obtained by the use of negative resistance devices, and any amount of damping can be easily introduced and measured.
4. Various types of response spectra can be obtained with the same device.

Using this electric analog technique, response spectra have been obtained for a series of strong-motion earthquakes in the western United States and general studies of the characteristics of such earthquakes have been made.

CHAPTER 6

SOIL CONDITIONS DURING SEISMIC SHOCKS

There are many examples of damage to structures caused by the change in the stress distribution in the ground or the change of the mechanical properties of the soil during earthquakes. Such examples include sliding of quay walls, settlement of embankments and building foundations and landslides. In the field of soil investigation, most of the work has been done in Japan.

In Japan, the intensity of earthquakes are classified into one of seven grades in the order of the extent of damages. Earthquakes of intensity V are classified as "Very Strong" and cause cracking of brick and plaster walls, damage to chimneys and damage to warehouse structures. Earthquakes of intensity VI are classified as "Disastrous" and cause the destruction of over one percent of all wood frame houses, landslides, and fissuring of level ground, accompanied by the emission of mud and water. Earthquakes of intensity VII (maximum) are classified as "Ruinous" and cause destruction of over 30 percent of all wood frame houses.

In other words, the superstructural damage caused by earthquakes of intensity V is considerably increased by earthquakes of intensity VI due to the greater damage suffered by the substructure. As earthquakes of intensity V have an average acceleration of 150 gals and those of intensity VI an average acceleration of 450 gals, it may be

presumed that the shearing strength of average soils is reduced considerably when the earthquake acceleration exceeds 300 gals approximately. Though not a confirmed fact, indications are that the characteristics of "Disastrous" earthquakes are different from those of lesser intensities. Two earthquakes, both having the same characteristics, except for the level of acceleration, could have different resultant damage aspects due to differing soil response.

Facts indicate that the properties of soils during vibrations are correlated closely to structural damage. Structural engineers should try to develop definite methods of dealing with seismic soil structures. However, at present there is very little knowledge as to the properties of soil structures during earthquakes. A few results of research on the fundamental properties of soil, the lateral pressure and the bearing capacity during vibrations have been utilized in the seismic design of embankments, retaining walls, quay walls, bridge foundations and other soil structures.

Mechanical Properties of Vibrating Soil:

In Japan, Dr. Takeo Mogami was the first to study the behavior of sandy and clayey soils subjected to vertical harmonic vibrations. He found that the shearing strength, or the yield value, of the soil is diminished by increasing the acceleration of the vibrations. In his series of experiments, a shear box was filled with sandy soil and vibrated vertically on a shaking table. Direct-shear tests were per-

formed and the shearing strengths measured under varying fibrations. The experiments indicated that during fibrations of the soil the shearing strength of the soil was correlated more to the acceleration than to any other factor. A typical relationship between acceleration and shearing strength of sandy soils is shown in Figure 14.

It is interesting to note that at an acceleration above 300 gals, the shearing strength of the sandy soil is reduced considerably to a state of almost "liquification". Shear tests were performed also on the soil called "Kanto Loam", and on disturbed and undisturbed clay samples obtained from the bottom of Yokohama harbor. In the case of the shear tests on clayey soil, the specimens began to yield at a shearing force defined as the yield value of this soil. Figure 15 shows the ratio of the yield values of clay for the case of dynamic testing and static testing against the accelerations of the vibrations. Figure 16 shows the yield values of Kanto Laom during vibrations with various water contents.

It is noted from these results that the yield value of the soil diminishes with the increasing acceleration of vibrations and the amount of the decrease is dependent upon the moisture content. Further, these results show that the amount of the decrease of the yield value is largest at the water content nearest the optimum moisture content. As the optimum moisture content of clay changes in value while vibrating from that at rest, it may be inferred that a soil

structure compacted while near the statical optimum is not always the most resistant possible to earthquake forces.

The lowering of the shearing strength of soil due to vibration seems to be related closely to the large damage suffered by structures from earthquakes of intensity VI. It is interesting to note that the critical value of acceleration, that causing liquification of soil, approximately coincides with the acceleration value of a disastrous earthquake. It is difficult to escape earthquake damage resulting directly from liquification of the soil. Therefore, it is the usual practice in Japan, in the regions where disastrous earthquakes can be expected, to place important structures on safer soils or to design them for the effects to be expected if they must be placed on suspect soils. This consists, for example, of extending building foundations to diluvial formations. Also, reinforced concrete piers are used instead of quay walls.

Below a certain limiting value of acceleration, the mechanical properties of soil do not change, practically speaking. Therefore, the stability of soil structures may be investigated analytically by analyzing the change of stress due to vibrations without considering the change in the mechanical properties.

Lateral Pressure of Soil During Vibrations:

Dr. Nagaho Mononobe and Dr. Saburo Okabe were the first to study the lateral earth pressure exerted on a retaining wall during an earthquake and proposed a procedure to estimate the value. In

using their method, superstructures and foundations are assumed to be acted upon statically by the resultant of the gravitational force and the maximum earthquake force. This method was then studied experimentally by Dr. Haruo Matsuo. A box having dimensions of 0.4 m x 0.4 m x 1.1 m and filled with dry sand was shaken horizontally on a shaking table and the lateral pressure on a wall of the box was measured by pressure gages attached to the wall. The period of vibration was 0.75 to 0.90 sec. and the maximum acceleration was 400 gals. Furthermore, similar experiments were repeated by Dr. Matsuo using larger sized boxes and all results agreed in general. The results showed that the increase of the pressure due to vibrations is much larger near the surface of the ground than at lower depths. This fact is a direct contradiction to Dr. Mononobe's assumption of linearly distributed pressure.

In 1953, members of the Japanese Transportation Technical Research Institute of the Ministry of Transportation built a large size vibration generator and constructed a large model retaining wall at a distance of 10.6 m from the generator. This wall was made of concrete, with a height and length of 3.0 m and 5.0 m, respectively. The vibration generator consists of a large elliptical concrete bowl buried in the ground, with principal diameters of 6.0 m and 4.4 m and a depth of 3.0 m. In this bowl is placed a mechanical vibrator which consists of two sets of unbalanced locomotive wheels. As the wheels are revolved,

the centrifugal force due to their unbalanced movements set the bowl in violent oscillation. The surrounding ground rocks similar to an earthquake with the vibrations being felt to a distance of one kilometer from the generator. The maximum angular velocity is 5.7 cps and the maximum vibrating force is 3.15 tons. The maximum horizontal acceleration measured at the top edge of the bowl is about 500 gals. The maximum horizontal acceleration recorded on the ground surface at a point 5.0 m from the edge of the bowl is about 370 gals.

The study on lateral earth pressure on the model retaining wall using this vibration generator has not been completely finished but preliminary results obtained so far indicate that the distribution of earth pressure on the wall during the vibration tests generally coincides with the results obtained by Matsuo's small scale experiments.

The seismic earth pressure of saturated soils on a retaining wall was studied by Dr. Matsuo and Mr. Sukeo Chara by model tests. They determined the existence of two kinds of water pressure produced by the pore water in the soil. They filled a box with saturated sand, vibrated it horizontally on a shaking table and measured the lateral pressure on a wall of the box. The distribution pressure of the saturated sand and water pressure on a retaining wall during vibration tests showed that the pressure increased as the depth of the soil increased. From the results of these tests it was noted that seismic hydraulic pressure exists and oscillates with the period of the exciting vibration force.

When the acceleration is increased gradually and exceeds about 200 gals, another kind of water pressure is noted. The soil undergoes consolidation with a sudden increase of the pore-water pressure. This is of practical importance, as the sudden increase of pore-water pressure due to vibration could be the cause of landslides and also of the spouting of sand and water during earthquakes.

The difficulty of determining the bearing capacity of the soil by field tests during an earthquake is apparent. Therefore, it is necessary to ascertain the value from the normal bearing capacity value determined by tests and calculations. For several years, a study on the effects of vibrations on the bearing capacity of sandy soil has been progressing in the applied mechanics laboratory of the Transportation Technical Research Institute of the Japanese government.

The test consists of a box filled with sandy soil placed on a shaking table and shaken horizontally. A test plate, loaded vertically, is placed on the surface of the sand. As the box is shaken horizontally, the vertically loaded plate settles into the sand. When the plate is loaded obliquely instead of vertically, the plate slides, due to shear failure of the soil beneath the plate before settlement begins. The settlement of vertically loaded plates under similar conditions has also been studied experimentally, in this country, by Prof. G. P. Tschebotarioff of the Highway Research Board.

In the Japanese tests, the dimensions of the test box were 15 cm width x 60 cm length and 30 cm depth. The test plate dimensions were 6.1 cm x 15 cm. The sand had a fineness modulus of 1.76, an average dry weight of 1.56 gm/cm^3 in the fairly dense state and the angle of internal friction ranged from 38 degrees to 50 degrees, according to the density. The shaking table period of vibration ranged from 1.35 to 0.33 sec, amplitudes ranged from 10 to 25 mm and the maximum acceleration was 380 gals.

It was found impossible to determine the exact bearing capacity when the acceleration of the vibration was more than 350 gals from dry sand and about 300 gals for saturated sand due to the violent motions near the surface of the sand. Up to these limits, it was found that the acceleration was the most decisive factor to the bearing capacity and in all cases as the acceleration increased, the bearing strength of the soil decreased. Near the upper limits of acceleration, the bearing value dropped off drastically.

When sand is saturated with water, the bearing capacity is reduced further. This may be caused by the decrease of the apparent specific gravity due to bouyancy and the relative increase of the ratio of seismic force to the gravitational force. The increase of the pore-water pressure due to vibrations has been determined by Matsuo, as mentioned previously, but its effect on the bearing capacity has not been quantitatively ascertained.

CHAPTER 7

FOUNDATIONS AND FOOTINGS

The response of structures to earthquake vibrations is the subject of study and research by many specialists. Seismologists record and interpret the amplitudes, accelerations and periods of seismic waves and locate their epicenters on active faults. Structural engineers analyze the shears and moments induced structures by seismic forces and design the structural members to resist these forces. As is well known, significant contributions to earthquake engineering have been made by research in these fields. In another specialized field of engineering, seismic design has been making progress.

The Mexican earthquake of July 28, 1957 brought many facts about earthquake design to light, and, from these facts, many practical suggestions can be made. The Mexican earthquake pointed out that, above all, sound foundation design is required when a structure is to be built in an earthquake zone. In fact, it can be stated that the foundation is the most important single factor in the design of earthquake resistant structures. The shocks of an earthquake must be transmitted to any structure by the soil in or on which it develops its bearing. A key factor that is within the control of the designer is the stabilization of the foundation of a building. The shocks may be damped or they may be magnified by the foundation before they are delivered to the superstructure.

Design For Vertical and Lateral Loads:

Failure of a structure is caused by excessive deflection, not excessive stresses. The same is true of foundation failures. However, the time-rate of deflection is more often of controlling importance in the design against foundation failure than in superstructure design.

First, the time-rate of settlement must be considered. For most soils, the amount of settlement will increase when the load is increased. This is assuming static loading conditions. For illustrative purposes, it is assumed that the building is supported on spread footings and that the structural engineer has specified the allowable total and differential settlements which the building can withstand; say one-half inch differential settlement between interior and exterior columns.

Settlement calculations are based on Terzaghi's Theory of Consolidation by which the compression of the foundation soils under the applied building loads is determined from theoretical curves. The time-rate of consolidation is dependent upon the rate at which water and air can escape from the voids of the soil subjected to pressures. This rate is relatively fast for sands and slow for saturated clays.

Next, the effect of seismic loads on the settlement behavior of this typical building must be considered. It is assumed that lateral earthquake loading has resulted in a 50 per cent increase in the vertical loads on the exterior column footings. In considering how the foundations

should be designed for the increased vertical loads due to these lateral forces, it might seem obvious that the exterior footings should be made 50 per cent larger to accommodate the combined vertical and seismic. However, this is not the case.

If the size of the exterior footings is increased because of seismic design considerations, while leaving the interior footings at the same size as required for support of dead loads, it must be determined what the effect on the settlement pattern of the building will be. Obviously, the settlement of the exterior footings under dead loads would be less than previously considered for the smaller footings and the differential settlements between exterior and interior columns would be increased.

This points to the fact that an apparent conflict exists in the design of foundations for vertical static and lateral seismic loads. To resolve this conflict, it is necessary to consider the difference in loading conditions for the vertical and lateral loads and the behavior of the foundation soils under these different conditions. First, it should be realized that the time duration of loading is very important in the response of foundation soils to loading. Design wind loads may be imposed frequently or for a sufficient length of time so that they can be considered similar to other live loads to which the structure is subjected. However, short time wind, seismic, or blast loads require a different concept of foundation design than used for conventional live loads.

One approach to the design of foundations for these short time loads is to permit an increase in the allowable bearing pressures. If there were a single magic number that could be used for this increase, whether it be 25 per cent, 33 per cent, 50 per cent or 100 per cent, foundation design would be greatly simplified. However, this easy solution is no more applicable to all different types of soil than a similar generalization would be to the various types of structural materials. Soil will react to short time loads in accordance with their varying physical properties. Generally speaking, sands are quite sensitive to these shock loads; clays are relatively insensitive. To better evaluate this, the load deflection characteristics of each soil type must be considered.

Load Settlement of Sandy Soils:

Sandy soils under load deflect at a fairly constant rate up to a certain point and after that point they deflect very rapidly. But, because of the fast drainage characteristics of sand, these settlements occur in a more or less straight line relationship. The magnitude of this settlement is primarily dependent upon the soil structure. For dense sandy soils, the magnitude of the deflection is relatively small; the magnitude of the deflection increases with the decreasing density of the sand deposit. If the density of a saturated sand is less than a certain critical value, the soil structure could collapse during a seismic disturbance, transferring the load to pore water and causing flow failure known as

liquefaction, as mentioned before. Some of the sensational flow slides of Holland and China have been due to this phenomenon. If this type of action is expected, the loose sandy soil should be stabilized or the structure should be supported independently of this soil stratum.

In establishing the allowable bearing pressures and also in estimating the foundation deflections for short term loads, the Japanese experiments on sandy soil should be taken into consideration. But, since the results of these experiments cannot duplicate actual site conditions, experience in the field of Soil Mechanics must be the principal guide to the engineer. Above all, it must be remembered that footings put on loose sands may yield or fail during seismic disturbances, even though their behavior under permanently applied vertical loads may have been satisfactory.

Buildings put on a dense sand formation may suffer no damage during an earthquake, even though the short time vertical loads may be much higher than those imposed permanently. Thus, some increase in bearing pressures for footings placed on dense, sandy soils may be permitted for short time seismic loads without sacrificing an adequate factor of safety against failure; a representative increase in allowable bearing pressure seismic forces is from 20 to 30 per cent.

Load Settlement of Clay Soils:

Generally, clays are less desirable foundation materials than sands because of their greater compressibility. However, clays do

possess some advantages over sands with respect to their behavior under short time loads. The settlement curve for permanently applied loads is similar in shape to that for sandy soils, although the magnitude of the deflection and the time-rate of its occurrence may be quite different, and the curve indicates more abrupt yielding at loads above the design range. However, a footing founded on clay would not exhibit appreciable deflection during a one-second seismic load, because the intergranular structure of the clay cannot adjust to the change of load during this short time. Although high pore pressures may be developed in the clay by the increased loads imposed during earthquakes, the time lag for consolidation of the clay will prevent appreciable deflections from occurring. Thus, footings on clayey soils may be designed for comparatively high, short-time loads without excessive deflection in the foundations. The allowable bearing pressures will be dependent upon the type of structure and upon the general characteristics of the soil. Again, experience and judgment rather than a precise laboratory testing procedure must, for the most part, be relied upon. For typical clayey soils, the allowable bearing pressures for dead plus live loads may be increased from 25 to 100 per cent for seismic loads.

The previous paragraphs should not be construed as advocating that the short-time vertical loads due to lateral forces can be ignored if the soils do not deflect appreciably under these loads. There is ample evidence that severe overstressing of the structural elements

of the foundation can occur, even though the same forces do not cause failure of the foundation soils. The Pacific Fire Rating Bureau has reported several examples of this behavior in elevated water tanks caused by the Arvin-Tehachapi, California earthquake of July 21, 1952. A typical example of foundation overstress occurred in the foundation of a 100,000-gallon water tank on a 100-foot high tower located at Maricopa Seed Farms about 15 miles southeast of Taft, California and 10 miles northwest of the epicenter of the quake. The anchor bolts were stretched and the concrete under the base plate was crushed. However, these high vertical loads did not cause any adverse effect on the foundation soils. The water tank at the Seed Farms was supported on friction piling because adequate support for the permanently applied loads could not be obtained by spread footings founded on the relatively weak sandy and silty subsoils. But the lack of foundation failure cannot be explained solely by the use of piling, as similar overstressing of the foundation connections has been observed in the case of tanks founded on spread footings. This example simply gives evidence to the fact that high vertical loads can be imposed during earthquakes, but that these loads would not necessarily cause detrimental deflection of the foundation.

Overturning Forces:

So far, only seismic loads which produce concentric pressure distributions on the foundation soils have been considered. In the design of foundations for tall stacks and vertical vessels, the assump-

tion of concentric pressure distribution under lateral loads is not valid.

Figure 17 depicts the theoretical and approximate pressure distributions on sandy soils for a rigid mat foundation supporting concentric vertical loads. As indicated by the theoretical pressure diagram, the highest pressure occurs under the center of the foundation, where the soils are confined by the surcharge effect of the imposed load as well as that of the overburden pressure. If the foundation is designed to impose average limiting pressures indicated by the approximate pressure diagram, the confinement is sufficient to prevent overstressing of the foundation soils.

When the stack is subjected to lateral loads, a redistribution of pressure occurs beneath the foundation as shown by Figure 18. Although the area of the trapezoid which approximates the eccentric pressure distribution may be no greater than the area of a rectangle representing the approximate concentric load pressures, failure of the foundation may be produced. The failure is caused by the fact that the concentration of pressure now occurs near the edge of the foundation where the effective confinement is produced only by the adjacent overburden. This confinement may be insufficient to prevent outward plastic flow of the overstressed soils and failure of the foundation may occur at the edges.

The effect of high edge pressures may be most critical under sustained wind loading conditions, but it also can produce foundation

failure during seismic loads. As the stack rocks on its foundation during an earthquake, progressive failure of the soil at the edges may occur. To prevent these adverse effects, the maximum edge pressures for overturning loads may be limited to a specified percentage of the design pressures for concentric loads. The theoretical pressure distribution for eccentric loads can be approximated by a trapezoidal diagram for which the maximum edge pressure should be limited to some percentage of pressures for concentric loads; 70 to 80 per cent are typical values for sandy soils. The pressure distribution for the mat foundation under these limiting seismic conditions is shown in Figure 19.

In clayey soils, the effect of high edge pressures is not as severe as it is on sandy soils, since the strength of clay is mainly a function of its intermolecular attraction, called cohesion, rather than of the internal friction which is dependent upon confining pressures. Generally, similar bearing pressures can be used for eccentric or concentric loading conditions on clayey soils.

Design of Piles:

Industrial buildings in reclaimed marshland areas often present special problems in seismic design. The presence of weak and compressible soils to considerable depths frequently requires pile supports of the structural frame and machinery of these buildings in order to avoid adverse settlement behavior. There are two possible methods

in approaching this problem. One approach assumes that the lateral force on the superstructure is transferred into the ground by means of the bending resistance of the piling. The alternate approach is to consider that the seismic forces are transmitted to the foundation by the ground motion rather than by the response of the superstructure. Recorded ground motion data seems to indicate that shear waves of large amplitudes and relatively slow velocities are created in extensive deposits of weak bay muds by earthquakes. When one considers that the ground surrounding the pile cap may deflect laterally as much as several inches in relation to the pile tip, it can be seen that the forces induced by ground displacements may be much greater than the forces transferred to the piling by an assumed lateral force applied to the superstructure. Thus, ground motion considerations may govern the foundation design for seismic forces.

In the design of pile foundations to resist the ground motion, it is impractical, if not impossible, to hold the structure in place while the ground moves in relation to the piles. What is important in seismic design is that the structure be well tied together so that the structure will not slide along the ground surface, but will move with the ground motion. To insure this behavior, the piles should be capable of deflecting with the ground displacements and the inertia forces set up in the building should be transmitted to the subsoils by evaluating the permissible lateral resistance offered by the soils adjacent to the pile caps and grade beams.

As another solution to the seismic design of pile supported structures, batter piles are sometimes considered. Although batter piles may be effective in resisting lateral loads applied above the ground surface, they are usually no more useful than vertical piles in resisting the lateral forces of ground motion. Also, in marshland areas, batter piles must resist the bending forces produced by subsiding fills, whereas only axial downdrag forces are produced on the vertical piles. As a result, batter piles may be more a disadvantage in foundations designed for both static and seismic loads under some soil conditions.

The stresses produced by earthquake shocks, for ease of analysis, are usually considered proportional to the weight of a building and its contents, and not to the surface area as in wind stresses; so the assumption that a building designed to resist wind loads will also resist earthquakes is not valid. In areas of earthquake shocks, an authoritative requirement for buildings on good foundations is a lateral load equal to 7-1/2 per cent of the weight of the building and its contents. This assumption should be used in conjunction with the requirements as set down in the California Administrative Code, Title 21.

When the field of foundation design is entered, it must be remembered that deep foundations are a valuable asset in an earthquake. Foundations should be substantial in design and well tied together. All concrete foundations should be well reinforced and the reinforcing from one unit should be carried well into connecting units. At all costs,

high soil pressures should be avoided, and particular attention should be given to the corner piers to give them ample bearing area against the earthquake effects which become quite concentrated in this area.

Building with towers or heavy cornices and buildings with very unequal distribution of mass are at a decided disadvantage in an earthquake and should be avoided. The various units, having different natural periods of vibration tend to batter against one another; the result being almost certain destruction, unless these units are properly framed to resist such action. Buildings or parts of buildings that are in contact but not bonded firmly together may sway with different periods. In that case, they are likely to separate and come together with a degree of violence sufficient to destroy them. It is, therefore, important that structures should be symmetrical in design and distribution of weight.

In general, it can be stated that for earthquake resistant structures:

1. reinforced concrete foundations and walls, particularly with diagonal reinforcing, be used when possible.
2. the corner bays of buildings have as few openings as possible.
3. the full depth of wall spandrel sections be used as beams.
4. the structural steel wall columns of I and H shape have their webs placed parallel with the walls.
5. end restraint, additional to that furnished by their connections to columns, be given the beams on column center lines, by means of extra reinforcing bars in the concrete floor slab across the column.

6. horizontal diagonal bracing be used between the floor beams attaching to an interior column.
7. particular attention be given to the corner wall columns of a building because such columns act as flanges of the vertical cantilever beams represented by the walls and hence will carry heavy direct stress in an earthquake.
8. for a similar reason, ample area to carry these column loads be given the footings of such corner columns.
9. foundation footings be well tied together at the footing level.

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APPENDIX A

Modified Mercalli Scale.

- I. Not felt except by a very few under especially favorable conditions.
- II. Felt only by a few persons at rest, especially on upper floors of buildings.
- III. Felt quite noticeably indoors, but many persons do not recognize it as an earthquake.
- IV. During the day felt indoors by many, outdoors by few. Dishes, windows, doors disturbed.
- V. Felt by nearly everyone; some dishes, windows and so forth, broken.
- VI. Felt by all; some heavy furniture moved, a few instances of fallen plaster or damaged chimneys.
- VII. Damage negligible in buildings of good design and construction; slight to moderate in ordinary well-built structures; considerable in poorly built or badly designed structures.
- VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures.
- IX. Damage considerable in specially designed structures; great in substantial buildings.
- X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed.
- XI. Few, if any, masonry structures remain standing.
- XII. Damage total

APPENDIX B

The California Administrative Code, Title 21, specifies that the amount of seismic force shall be not less than that given by the formula.

$$F = CW$$

where

- F = seismic force applied (pounds)
- C = a coefficient which varies with the part or portion of the building or structure, and with the seismic probability of the geographical area.
- W = total dead load tributary to the portion under consideration. Live load or percentages of live load are included for certain types of structures such as warehouses and tanks, and Title 21 requires that one half of that portion of the snow load which exceeds 20 pounds per square foot be included.

The coefficients C have been determined by the observations and measurements of the effects of past earthquakes on various buildings.

The values of the coefficient C prescribed by Title 21 are given in the following tabulation:

Title 21 Values of Coefficient "C"

Part of Portion	Value of C	Directions of force
Floors, roofs, columns and bracing in any story of a building or the structure as a whole	.06 n + 4.5*	Any direction horizontally
Bearing walls, nonbearing walls, partitions, free standing masonry and concrete walls over 5 feet in height.	.20 With a minimum of 5 psi	Normal to surface of wall
Cantilever parapet and other cantilever walls above roofs of buildings.	1.00	Normal to surface of wall
Exterior and interior ornamentations and appendages	1.00	Any direction horizontally
When connected to or a part of a building: towers, tanks, towers and tanks plus contents, chimneys, smokestacks and penthouses.	.20	Any direction horizontally

Part or Portion	Value of C	Direction of force
Elevated Water tanks and other tower supported structures not supported by a building	.12	Any direction horizontally
Anchorage and foundations of such structures	.20	

*N is the number of stories above the story under consideration, provided that the floors or horizontal bracing, N shall be only the number of stories contributing loads. This factor shall be applied to the summation of all required loads above the story under consideration. N is equal to 0 for one-story buildings.

APPENDIX C

SMAC STRONG MOTION ACCELEROGRAPH

- I. Three accelerometer pendulums set at right angles to each other.
- II. A spring motor for driving the record paper.
- III. A time marking clock.
- IV. An electric starter. All of these parts are mounted on a rigid iron base which in turn is bolted to a concrete pedestal.

An outline of these vital components of this accelerograph is tabulated as follows:

1. Accelerometer proper.
 - a. Type: Pendulum type accelerometer with its bob of 4.3 kg in weight acting as the piston of the air damper.
 - b. Proper period: 0.1 sec.
 - c. Sensitivity: 25 gals. per mm. on the record.
 - d. Damping: Critical.
 - e. Working range: 10 to 1000 gals.
 - f. Record paper: Special wax paper, 24 CM x 10 m.
 - g. Recording speed: 1 cm. per sec.
2. Driving spring motor.
 - a. Type: Hand-wound spring motor.
 - b. Action: Starts 3 times. 3 minutes running time for each start.
 - c. Governor: Centrifugal, quick-accelerating.
3. Time-marking clock.
 - a. Type: Hand-wound clock with electric contacts.
 - b. Time marks: Every one sec., or 1/5 sec., interchangeable.

4. Electric starter.

- a. Type: A vertical component pendulum with a period of
0.3 sec.
- b. Action: operates at 10 gals.
- c. Electric contact: 3 pairs of platinum contact points in
parallel.

Figure 1

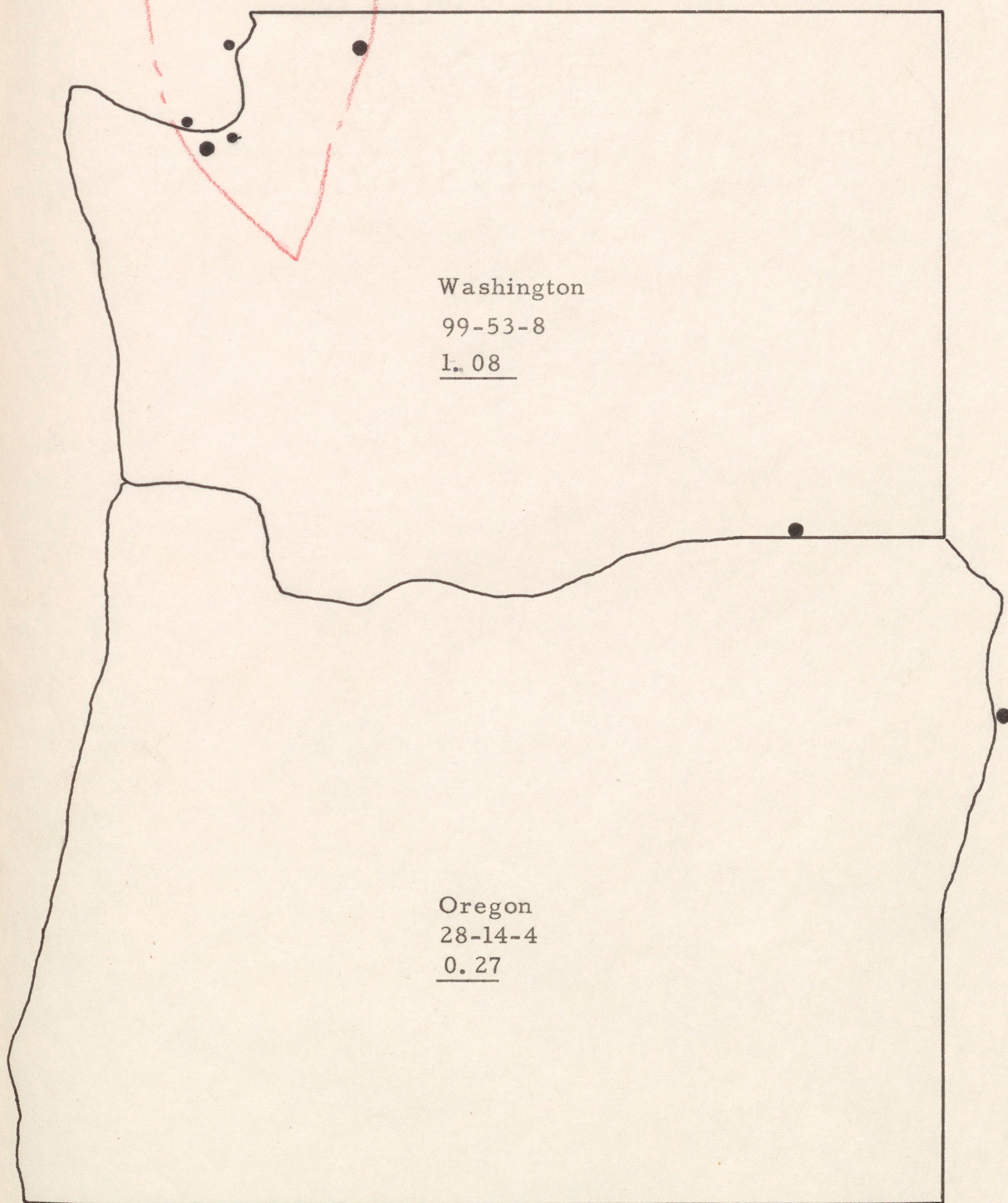


Figure 2

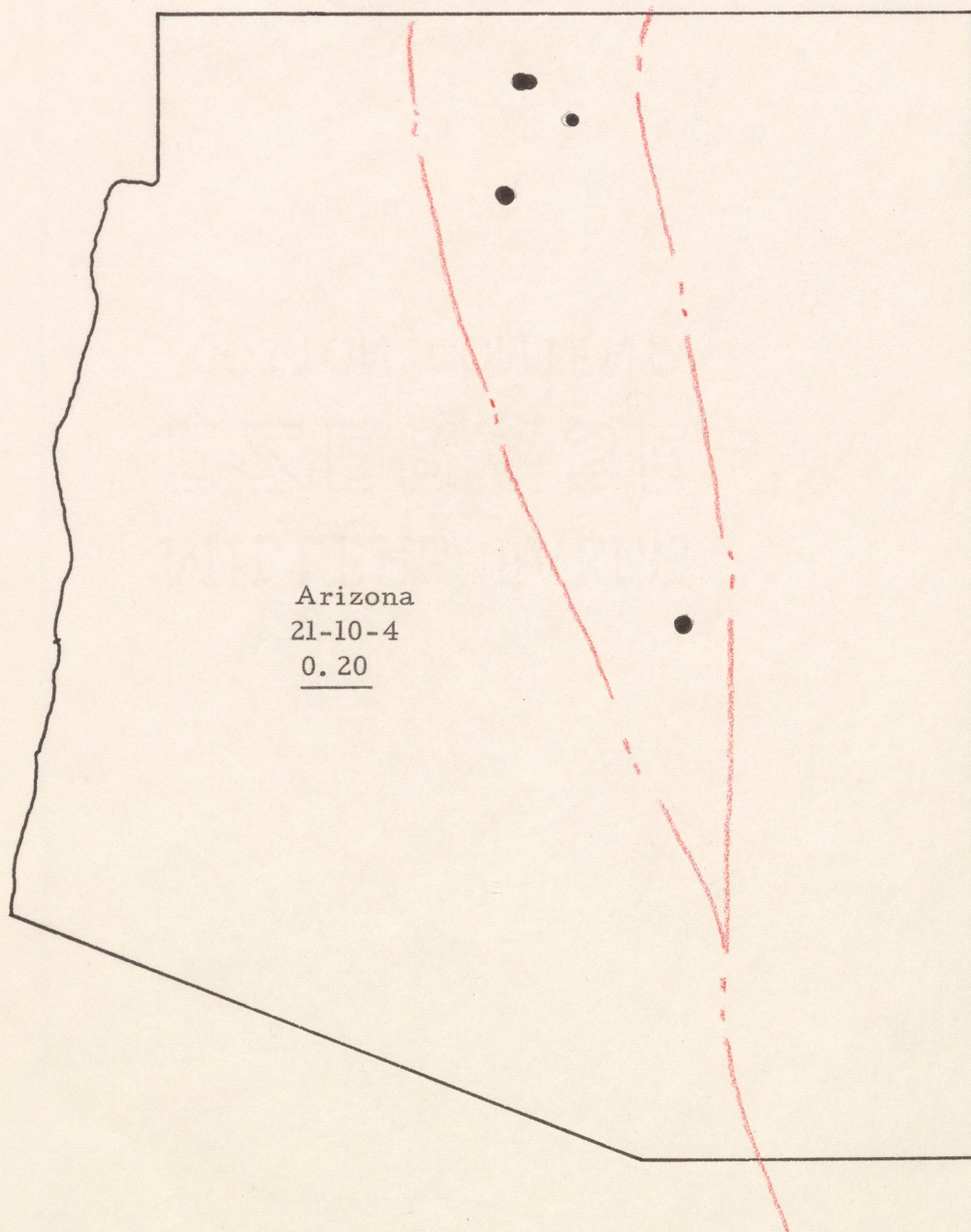


Figure 3

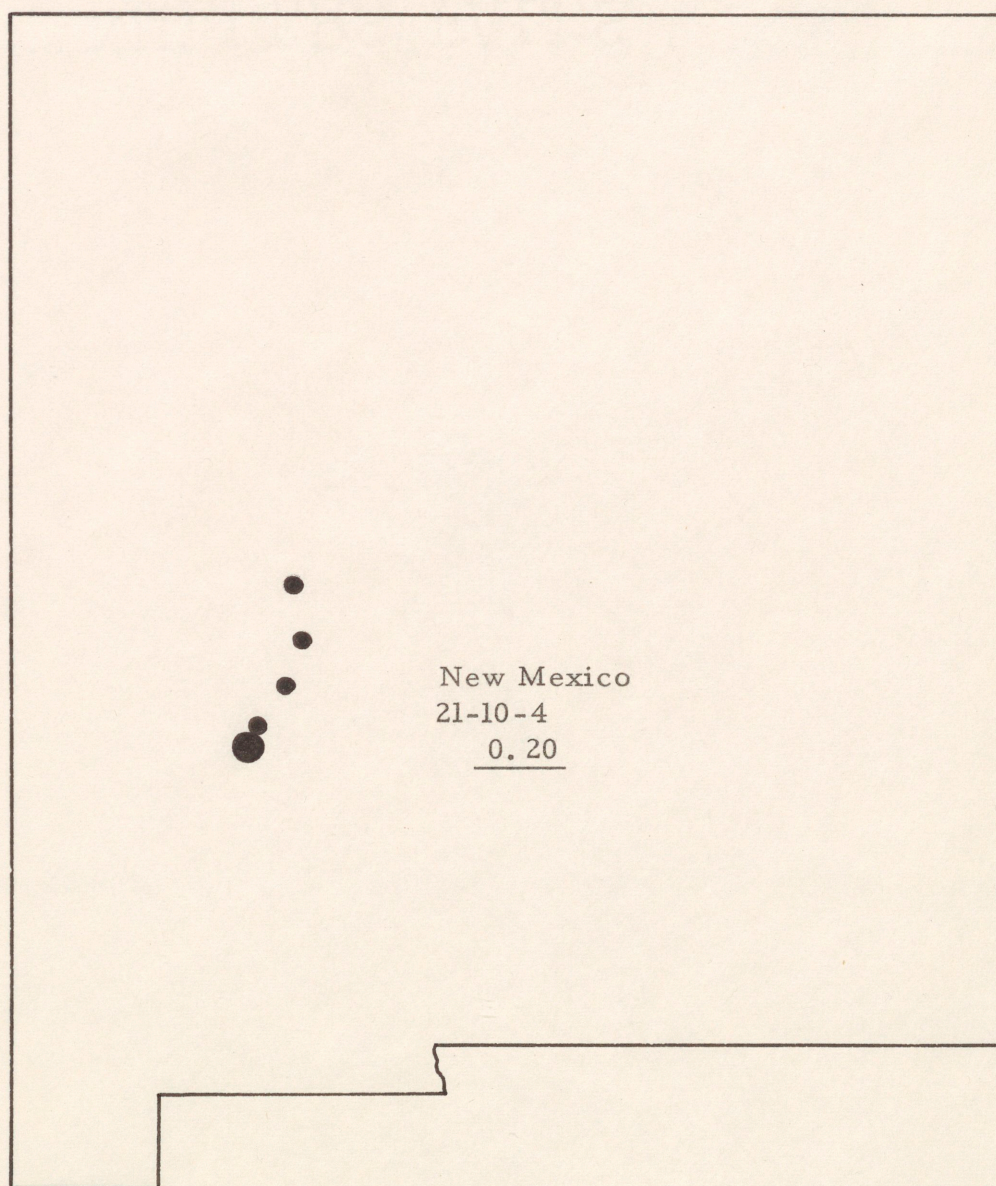


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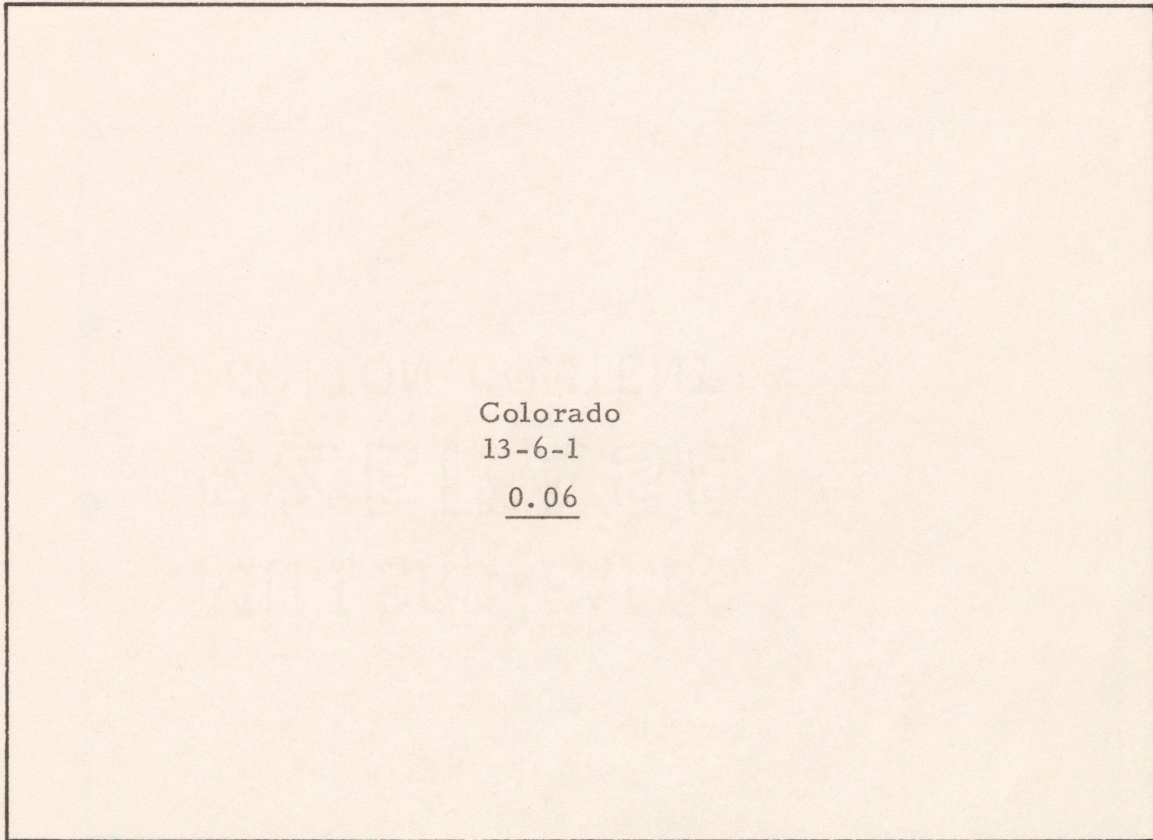


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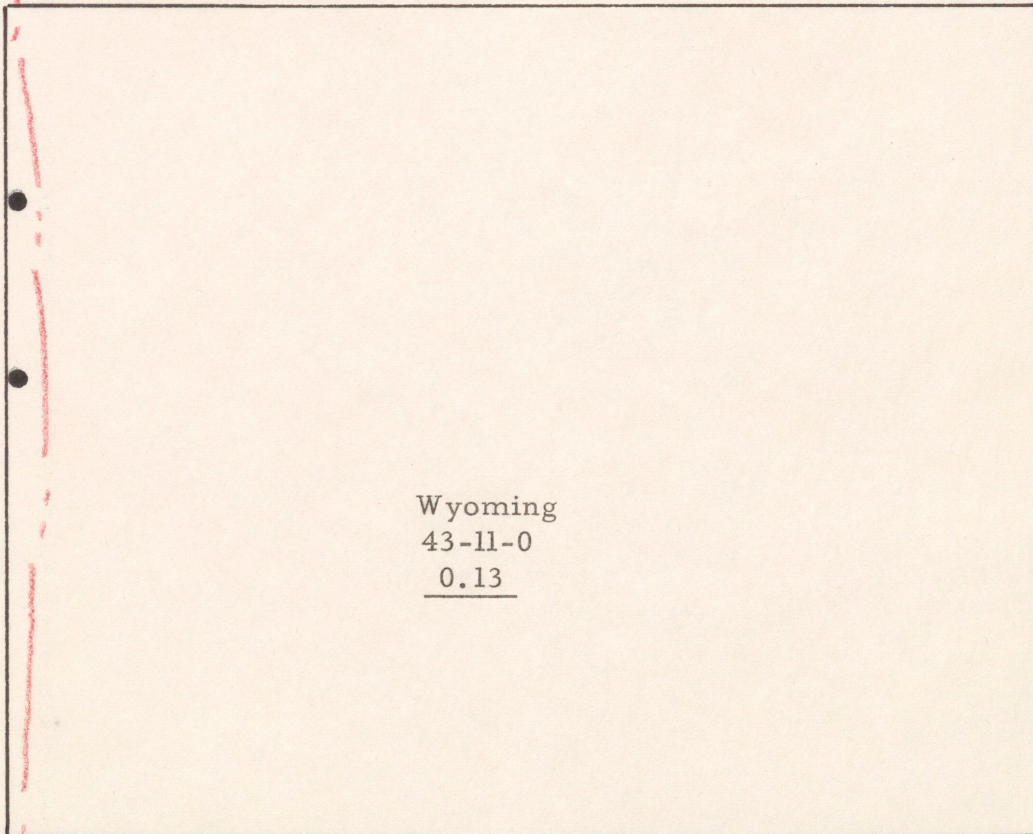


Figure 6

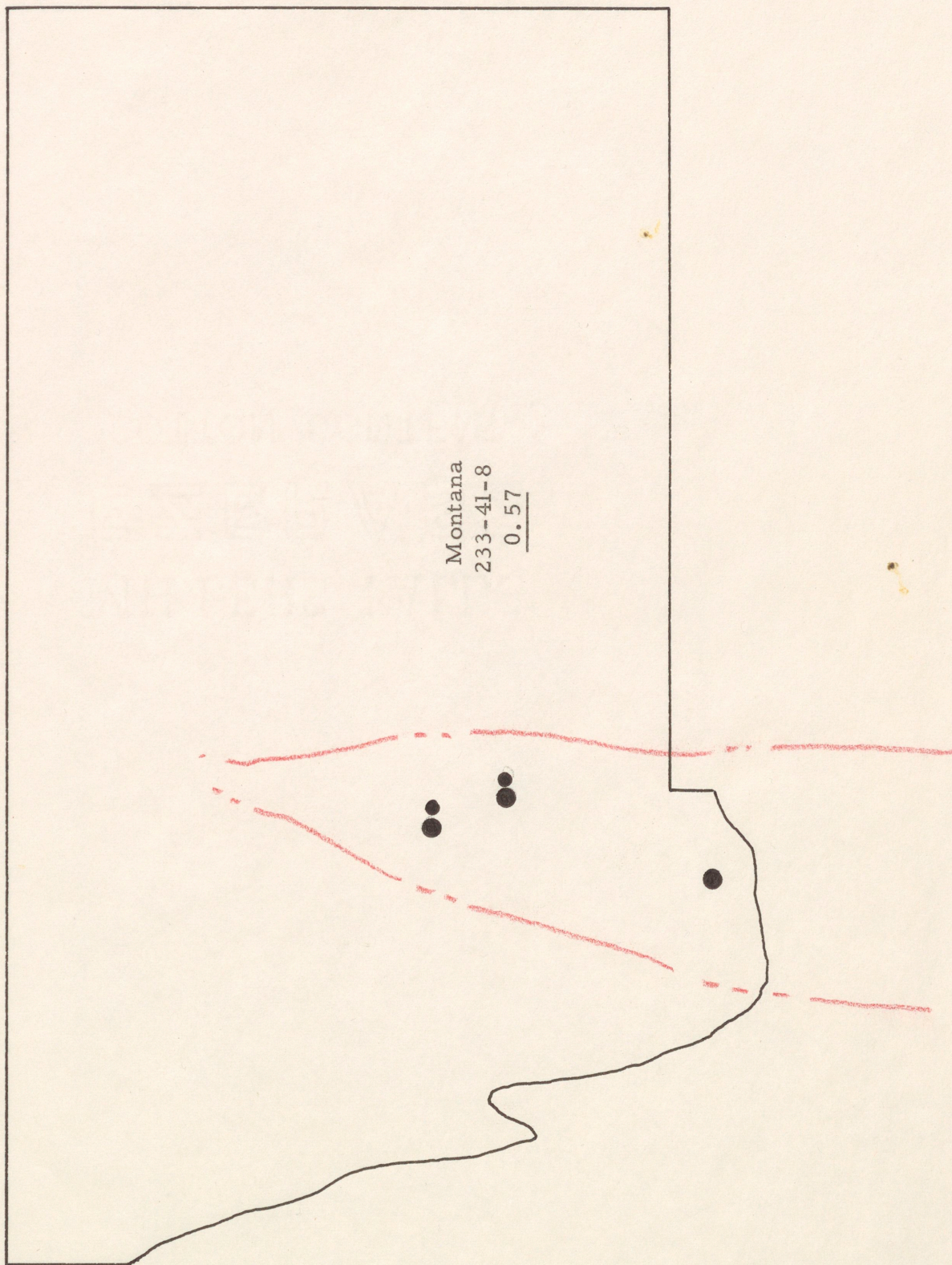


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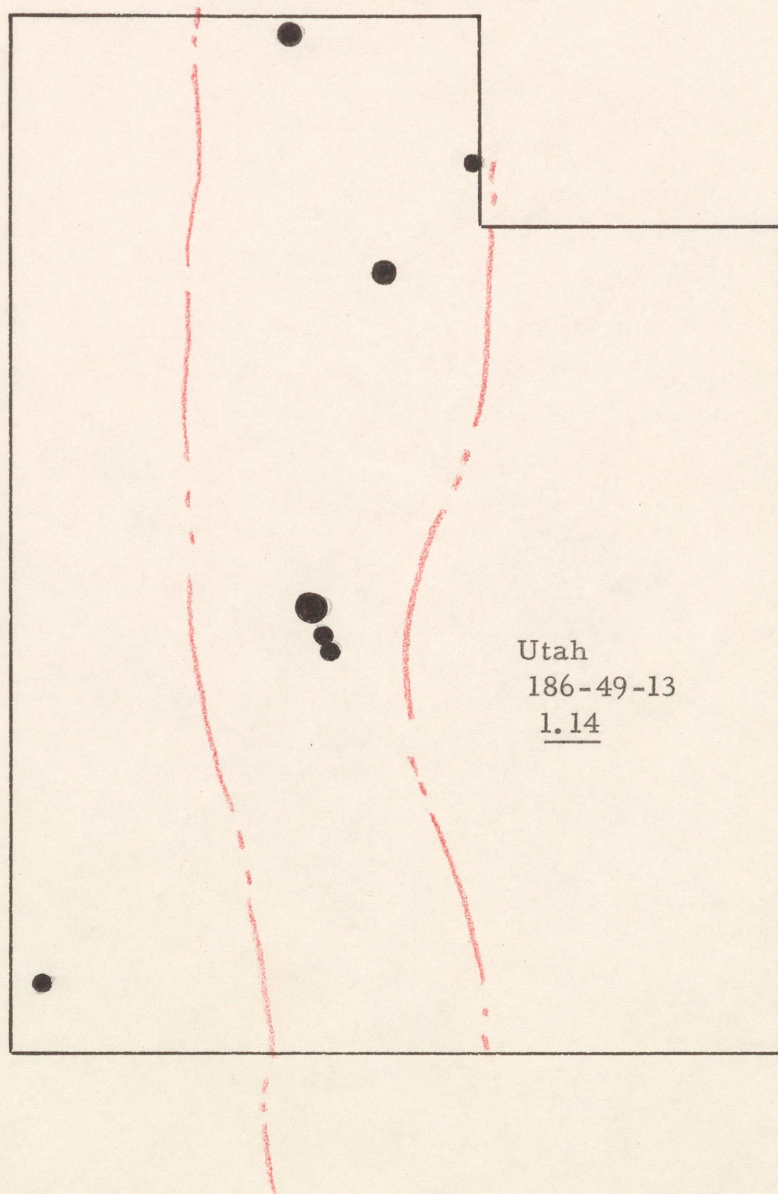


Figure 8

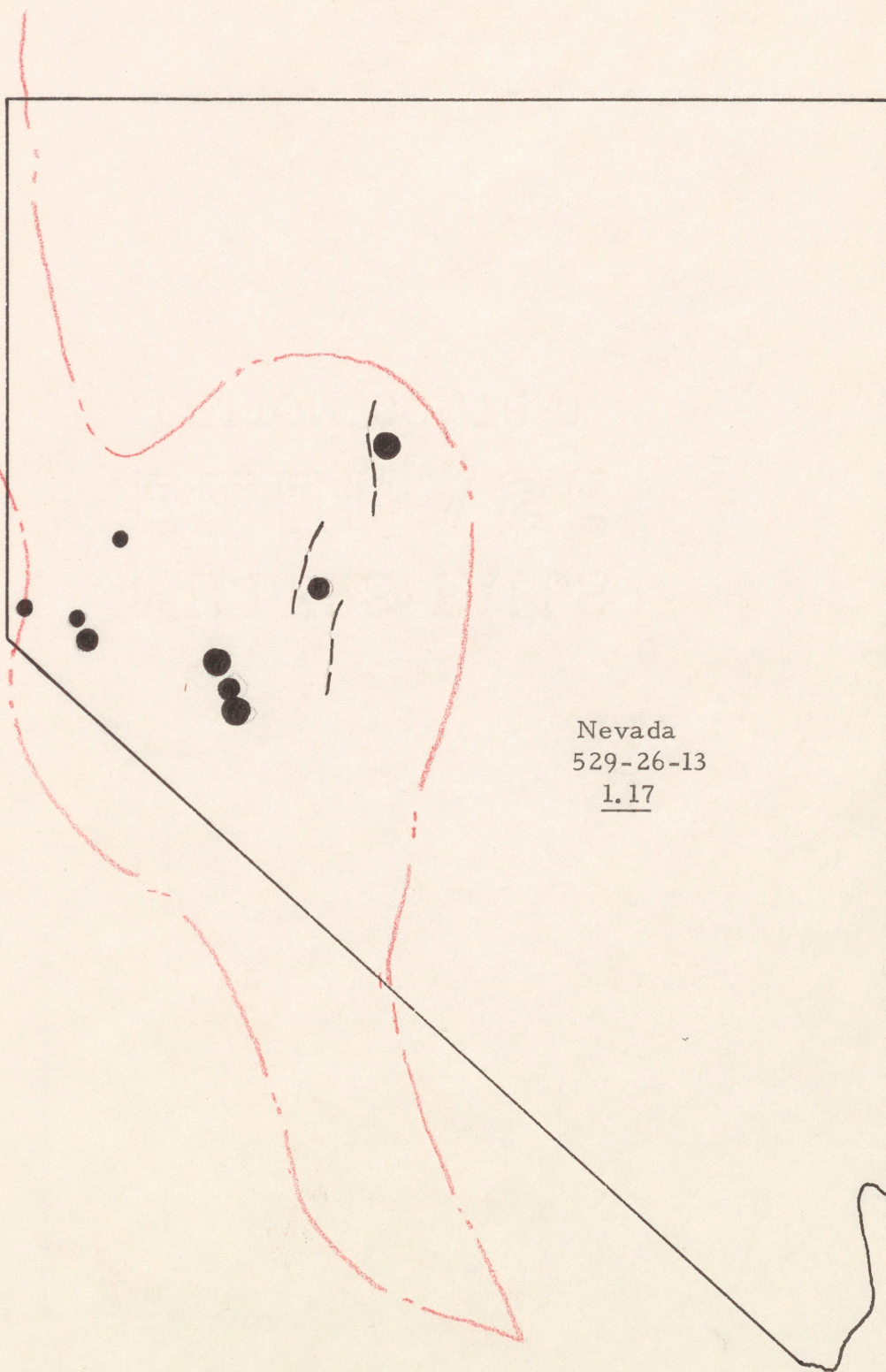


Figure 9

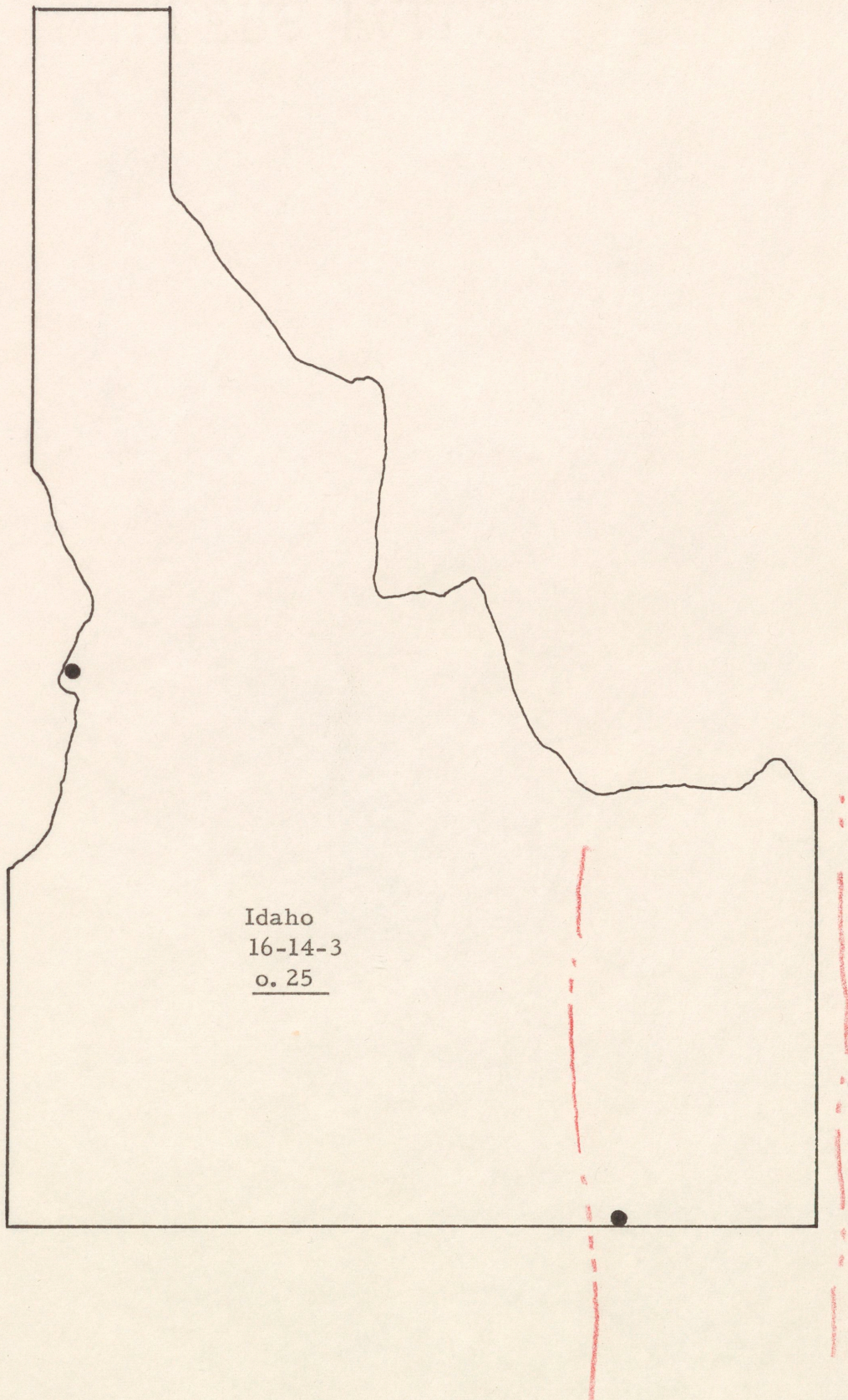
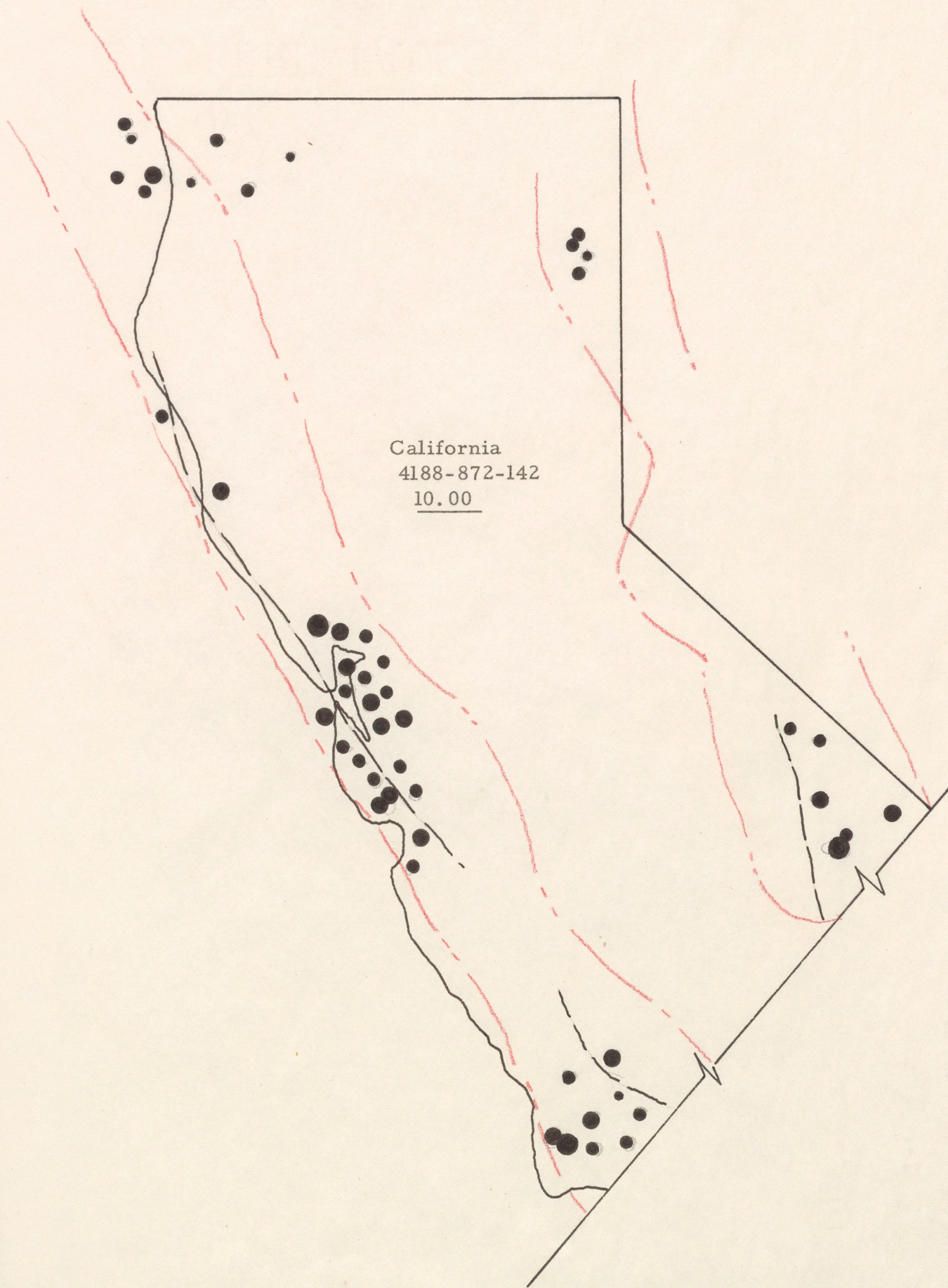
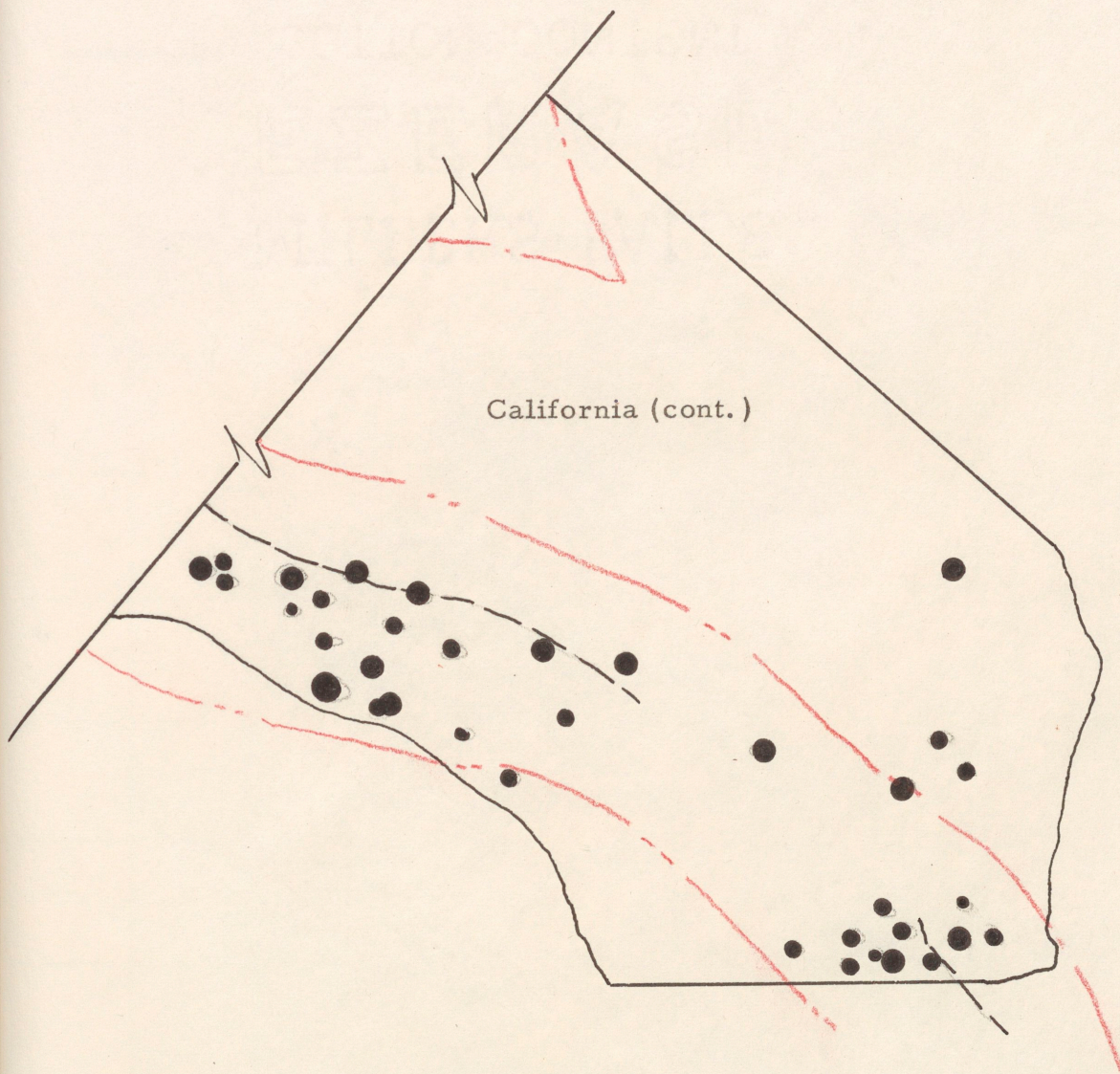
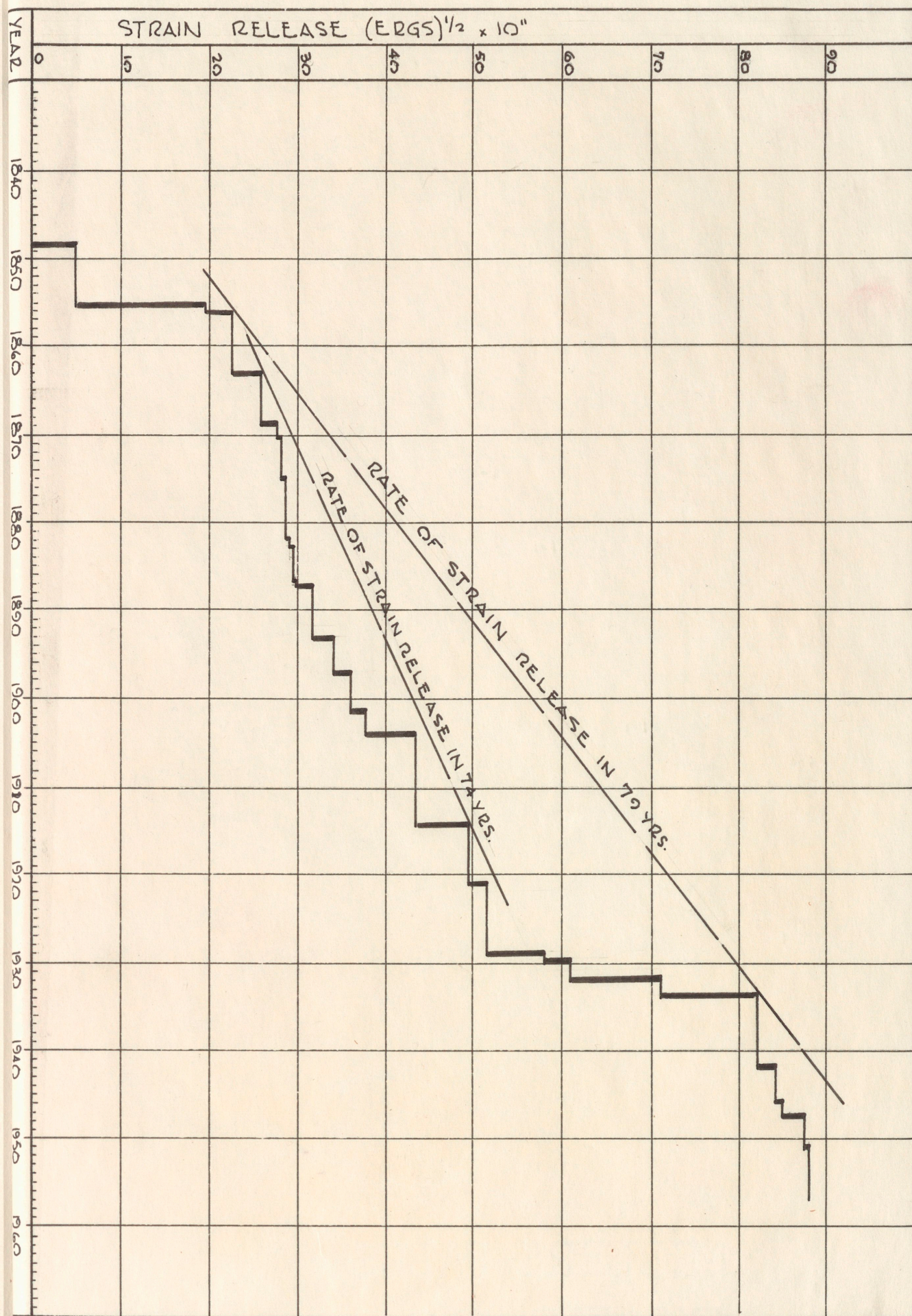


Figure 10



California (cont.)





TYPICAL ACCELEROGRAPH RECORD

Taken by Instruments of the
U. S. Coast and Geodetic Survey

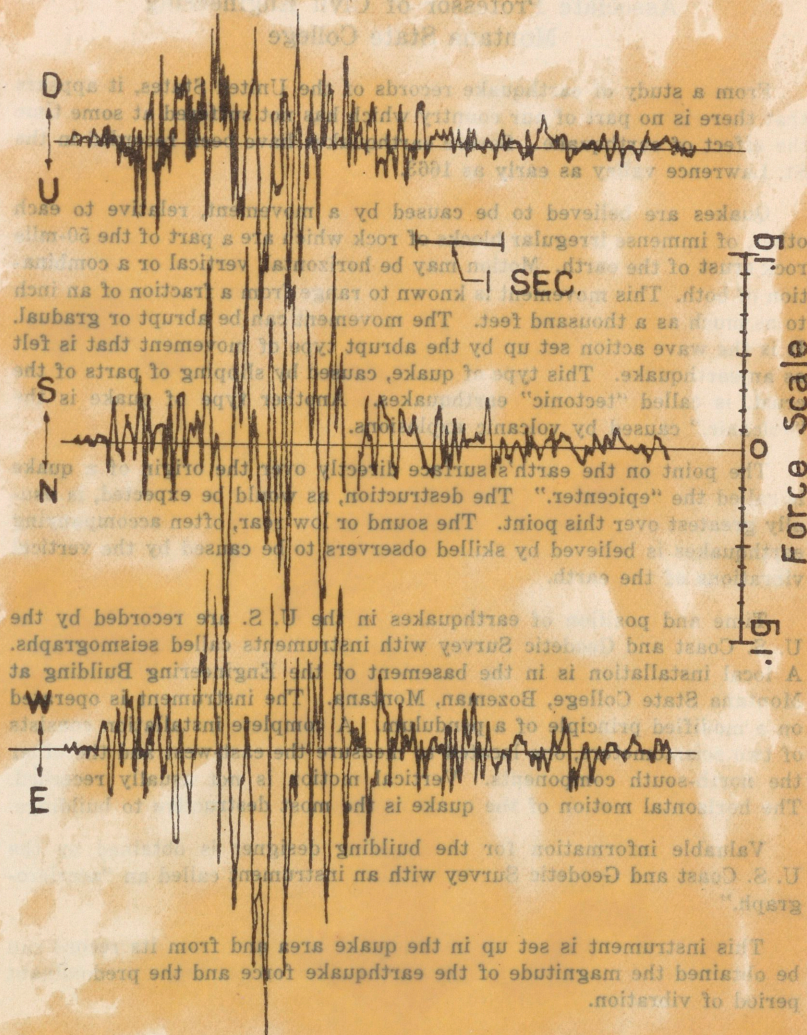
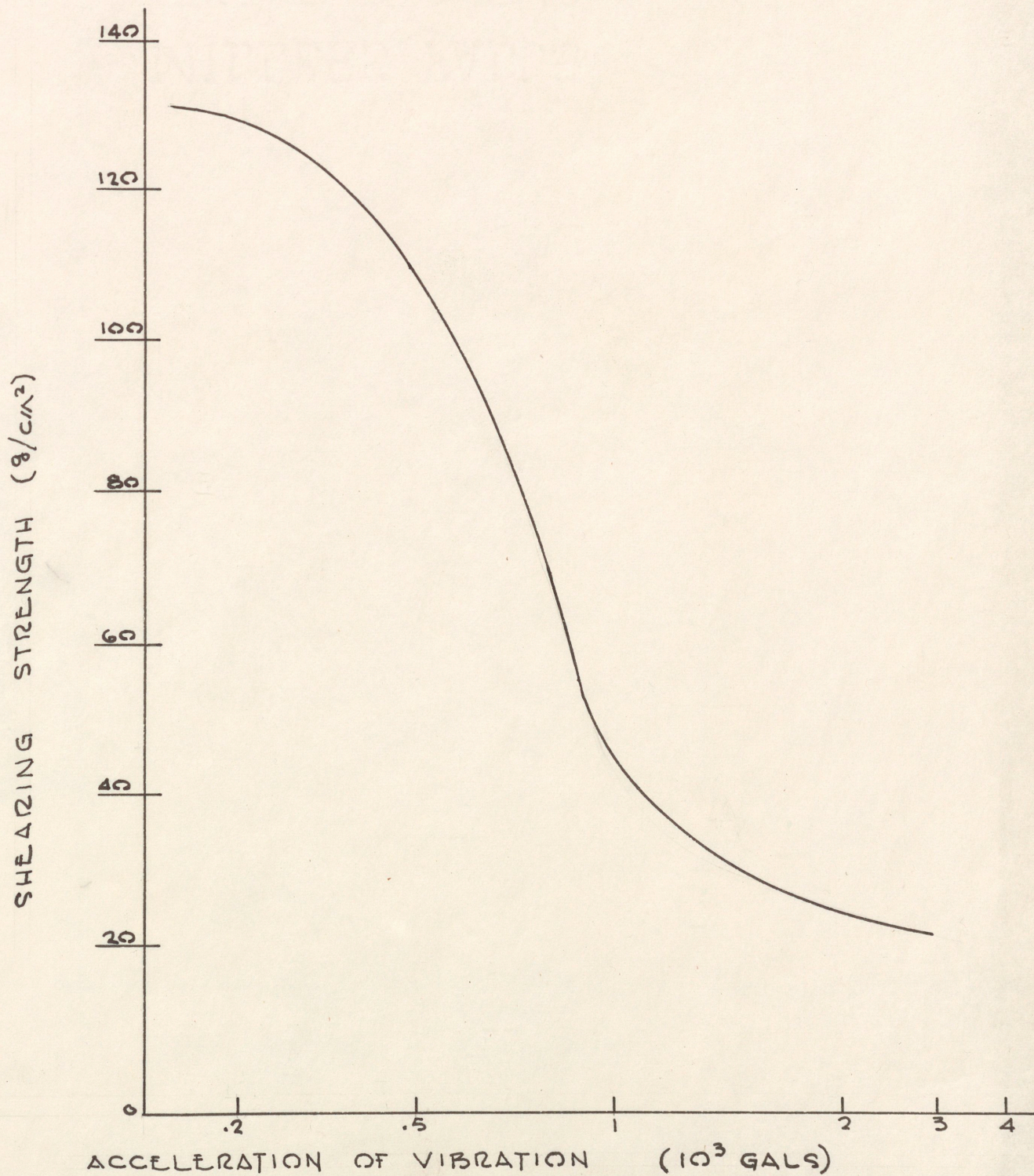
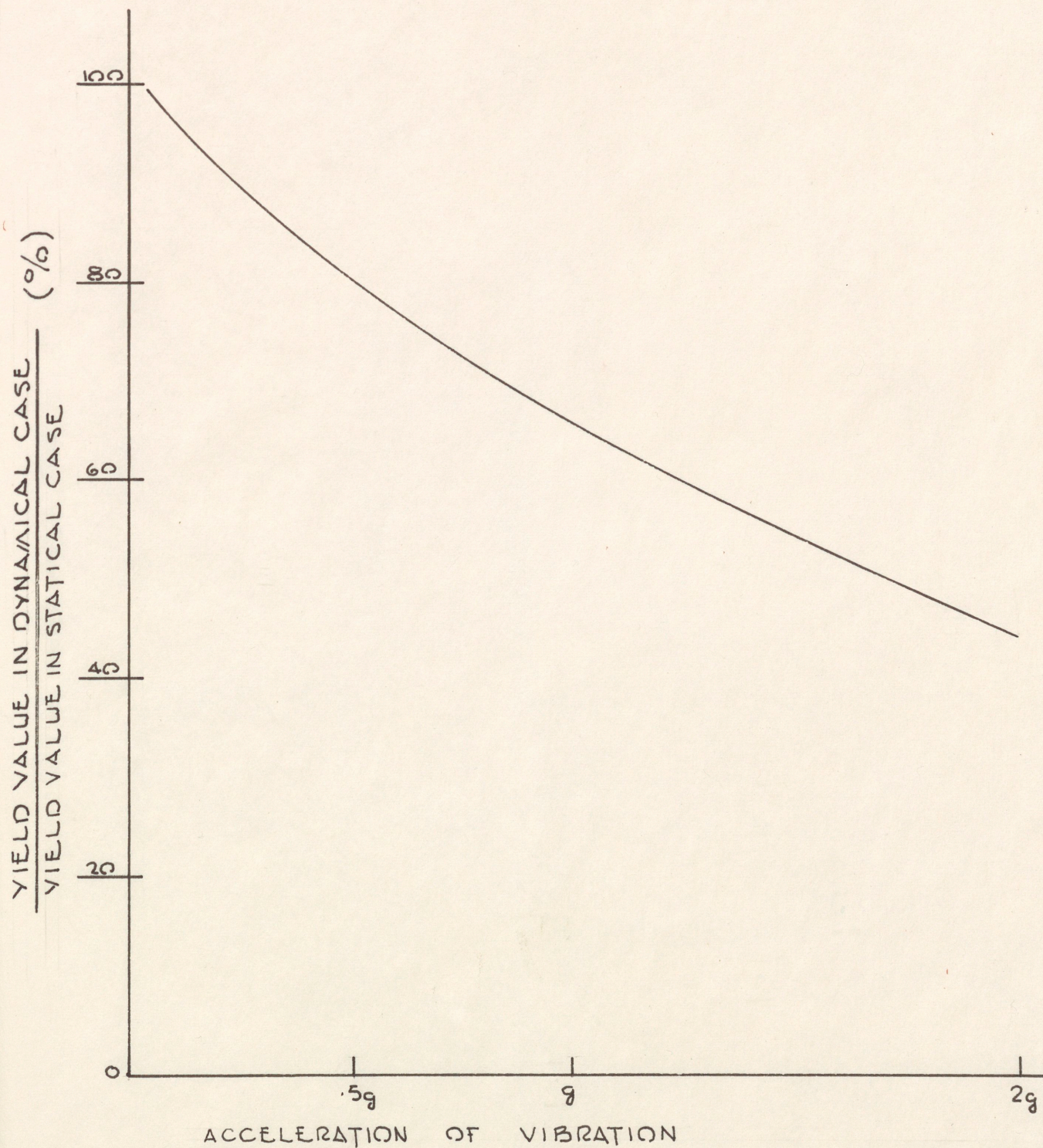
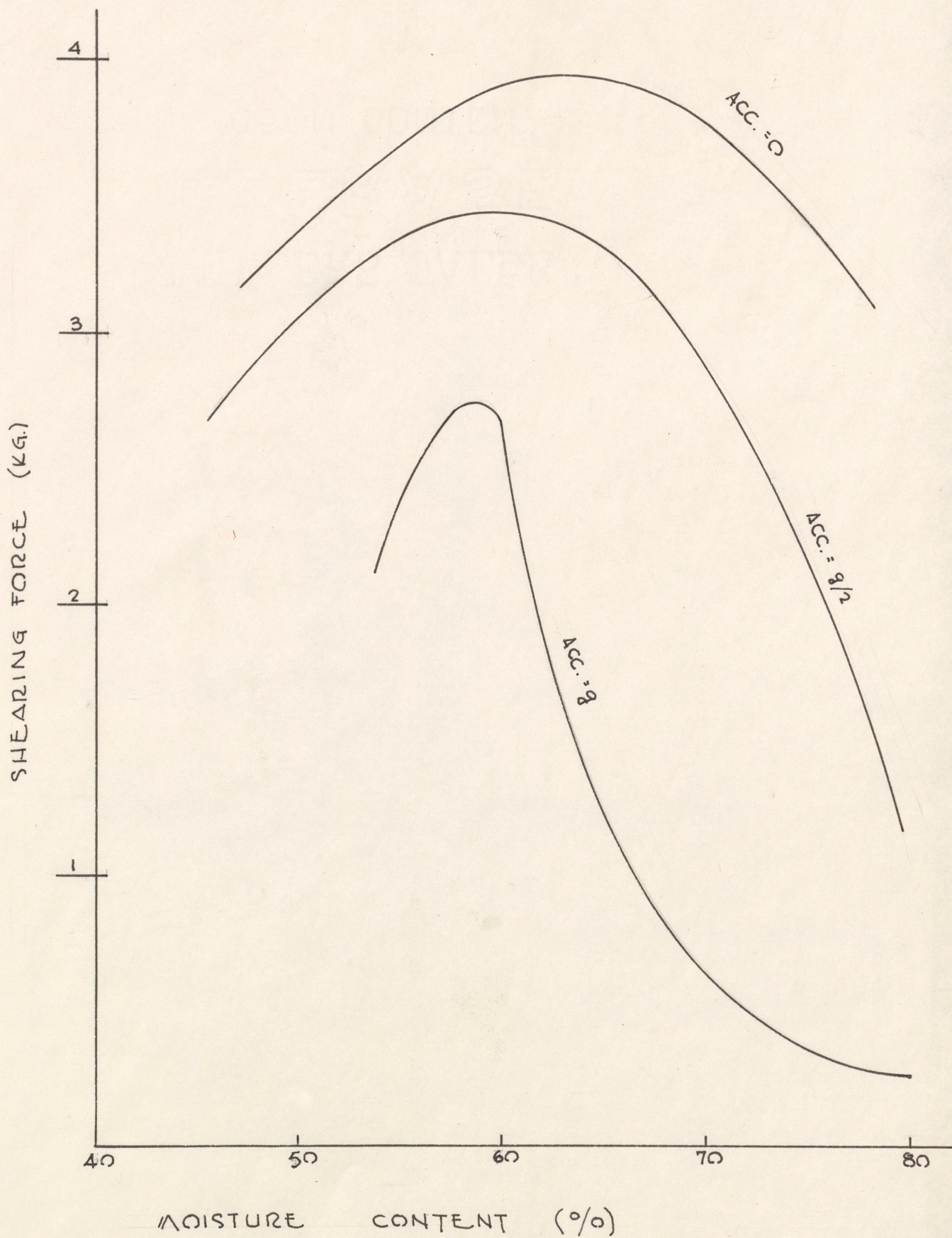
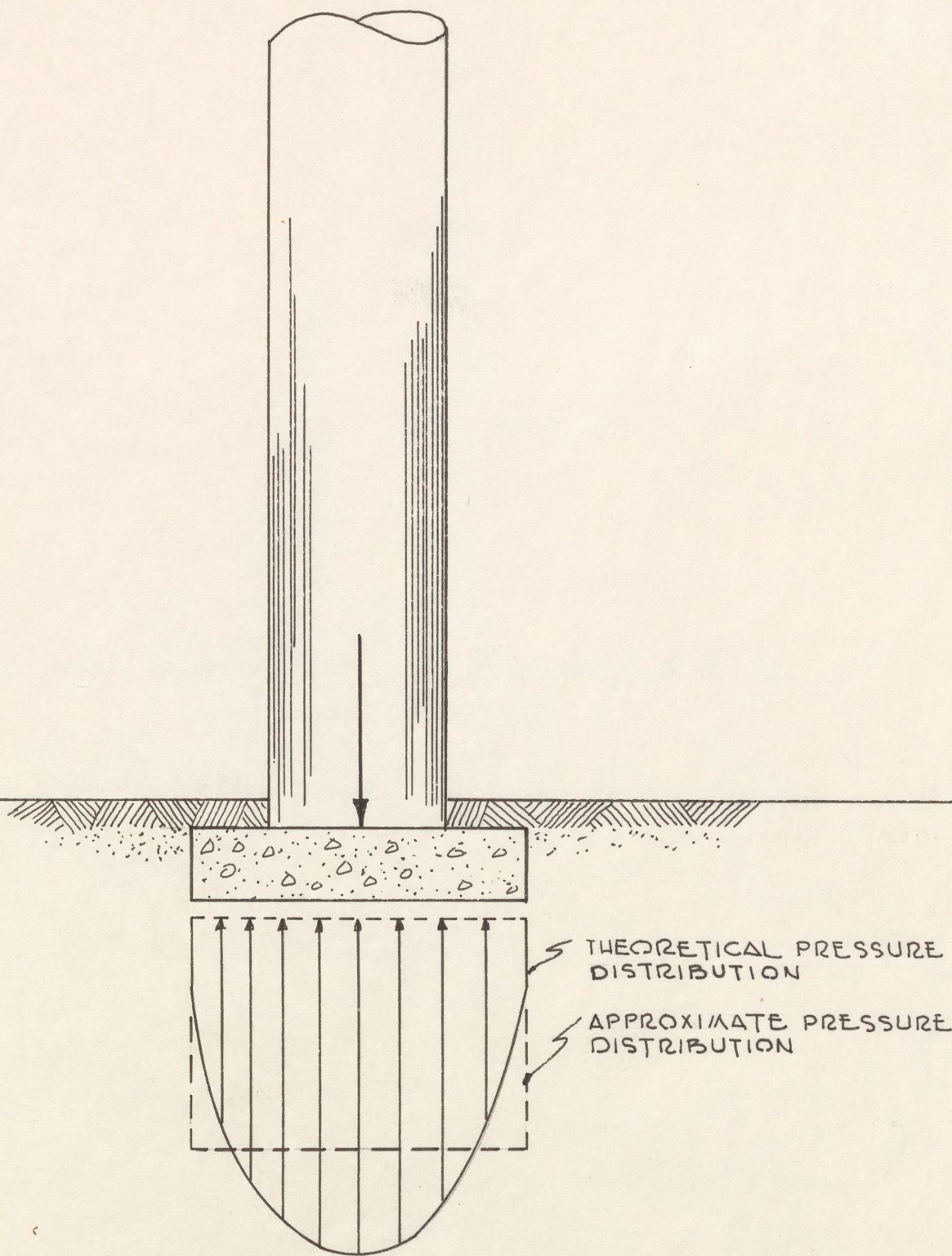


Fig. 1

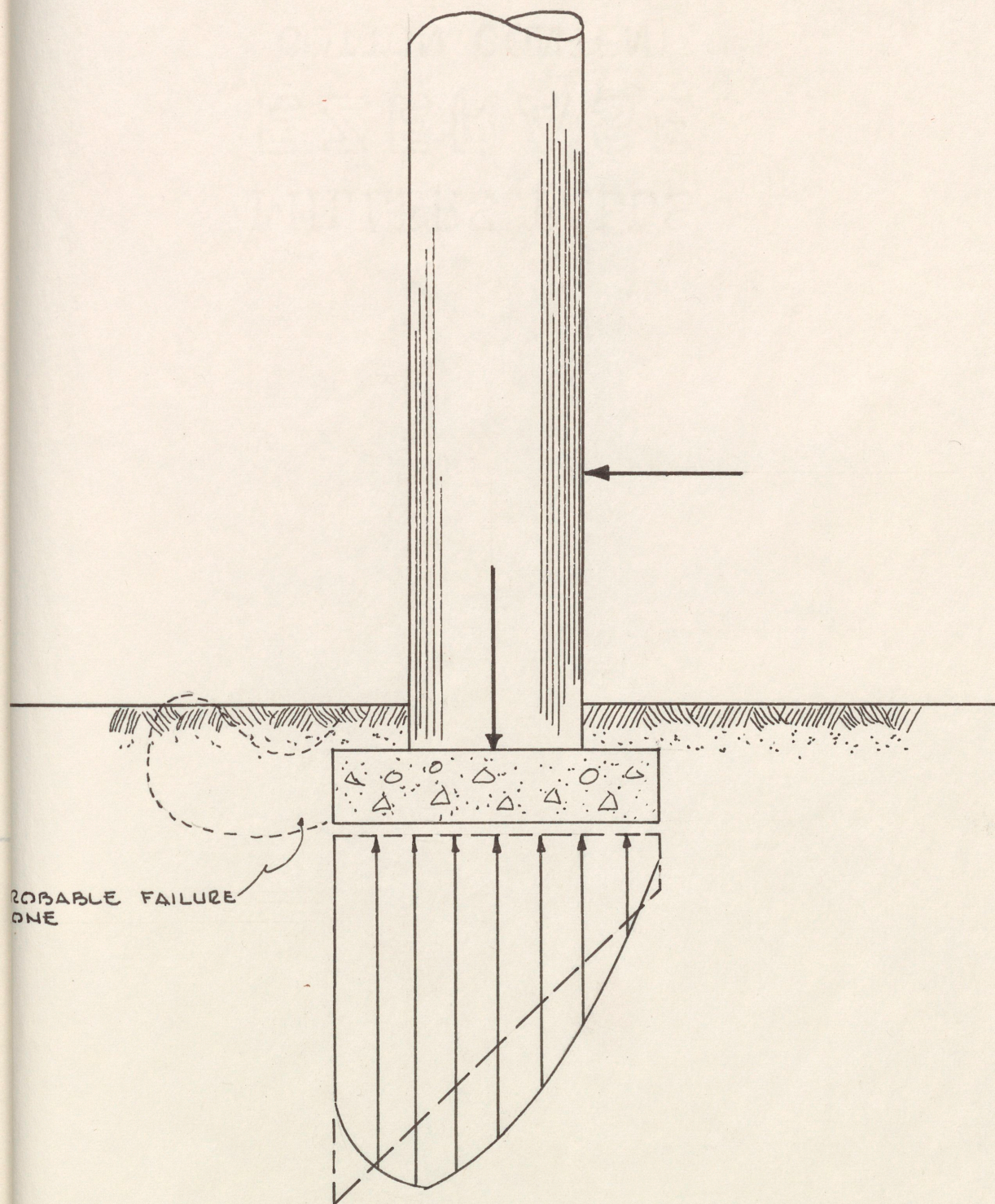




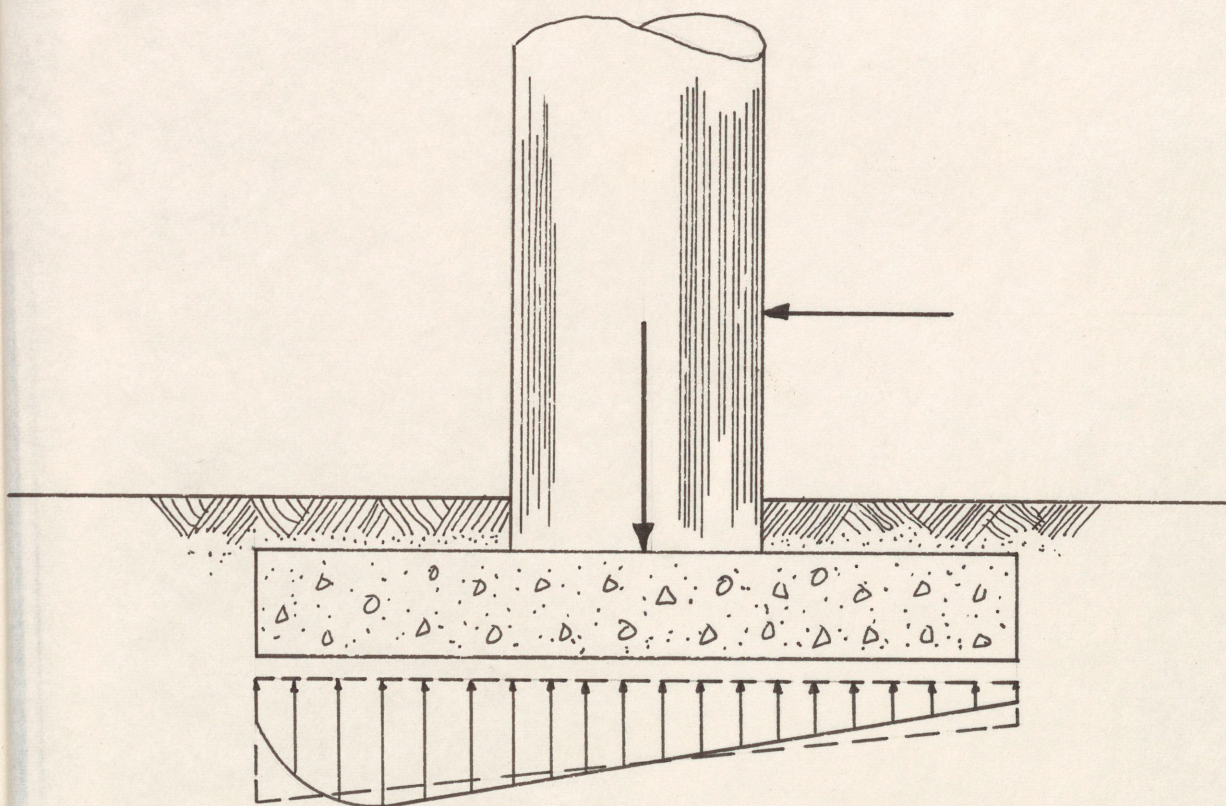




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STATIC CONDITIONS



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